#### **General Disclaimer**

#### One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some
  of the material. However, it is the best reproduction available from the original
  submission.

Produced by the NASA Center for Aerospace Information (CASI)

(NASA-CK-108942) SIUEY OF REACTOR BRAYTON POWER SYSTEMS FOR RUCLLAR ELECTRIC SPACECRAFT (AIRCSEGION MIG. CO., PROGRIX, ALIZ.) 169 p HC AUS/MF AU1 CSCL 210

N82-24289

Unclas 63/20 21545

# STUDY OF REACTOR BRAYTON POWER SYSTEMS FOR NUCLEAR ELECTRIC SPACECRAFT

**FOR** 

CALIFORNIA INSTITUTE OF TECHNOLOGY

JET PROPULSION LABORATORY

**CONTRACT 955008** 

**SEPTEMBER 28, 1979** 



AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A Division of The Garrett Corporation Phoenix, Arizona

31-3321

### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVIDIO OF THE SARREY COMPANY OF ARIZONA PHOENIX, ARIZONA

## TECHNICAL REPORT STUDY OF REACTOR BRAYTON POWER SYSTEMS FOR NUCLEAR ELECTRIC SPACECRAFT

31-3321

September 28, 1979

Approved by: Allen Harger

A. Harper, Study Manager

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A Division of The Garrett Corporation P. O. Box 5217 Phoenix, Arizona 85010

ORIGINAL CONTAINS

6510H 1244 AFFERIORS

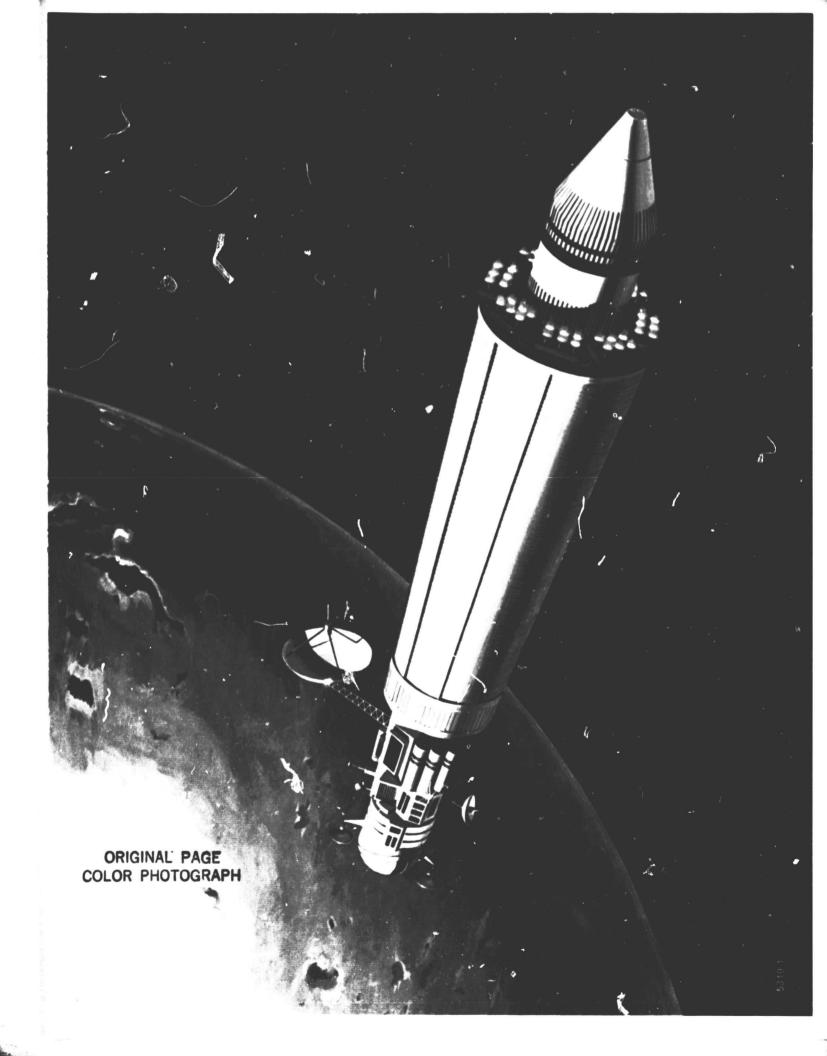
 REPORT NO.
 31-3321

 TOTAL PAGES
 77

ATTACHMENTS:

Appendices: Thermacore Heat-Pipe Data LASL Reactor Data

RE∨	BY	APPROVED	DATE	PAGES AND/OR PARAGRAPHS AFFECTED
and the state of t				





### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA

#### SUMMARY

The study of Brayton power systems for nuclear electric space-craft was performed to provide a basis for comparison between this system and others that have been under study for some time. Most significantly, this initial study has yielded performance parameters for the Brayton system that are very competitive with the alternative systems and envelope dimensions that are compatible with the Space Shuttle payload bay.

The primary performance parameters of system mass and radiator area were determined for systems from 100 to 1000 kWe. Mathomatical models of all system components were used to determine masses and volumes. Two completely independent systems provide propulsion power so that no single-point failure can jeopardize a mission. The waste heat radiators utilize armored heat pipes to limit meteorite puncture. The armor thickness was statistically determined to achieve the required probability of survival.

A 400-kW<sub>e</sub> reference system received primary attention as required by the contract. The components of this system were defined and a conceptual layout was developed with encouraging results. An arrangement with redundant 400-kW<sub>e</sub> Brayton power systems having a 1500°K (2240°F) turbine inlet temperature (TIT) was shown to be compatible with the dimensions of the Space Shuttle orbiter payload bay. The spacecraft is deployed from within the cylindrical primary radiator in a manner similar to the present Jet Propulsion Laboratory (JPL) thermionic system design. The preliminary mass determination for the complete power system is close to the desired 20 kg/kW<sub>e</sub> for the specified Jovian environment. With further refinement, that the current Brayton conceptual design can better this goal. Study results have also shown that use of more advanced technology (higher TIT) will substantially improve system performance characteristics.

#### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA PHOENIX, ARIZONA

Because certain near-term missions with nuclear electric power systems are of present interest, a preliminary design concept of a 100-kW Brayton system was also developed. This system was designed with essentially current Brayton technology (i.e., TIT = 1325°K) for operation in the geostationary orbital environment. A flight version of this system could be available by the late 1980s.

Further studies and analyses of refined nuclear reactor Brayton space power systems are recommended for continued attention. Brayton system technology efforts should be undertaken in the near future to assure a proper base for development of flight systems in the late 1980s and 1990s.



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE ABBRETT EXEMPLISH PHOENIX, ARIZONA

#### **ACKNOWLEDGEMENTS**

The excellent working relationship which has been established with JPL has contributed substantially to this study. Especially recognized are the efforts of Wayne Phillips, who was technical manager of the study, Jack Mondt, Leader of the Nuclear Thermal to Electric Power Group, and Teh Hsieh, who monitored technical aspects throughout this study. The support of James Lazar and Jerome Mullin of the NASA Office of Aeronautics and Space Technology Space Power and Propulsion Division is greatly appreciated. The continuing interest of Mr. Robert English of the NASA Lewis Research Center has been very helpful and is acknowledged with much appreciation.

In support of this study. JPL arranged for data to be provided by the Los Alamos Scientific Laboratory (Dave Buden, Dan Koenig and Ken Cooper) and by Thermacore, Inc. (Yale Eastman and Don Ernst). The extensive dialog and numerous meetings with the above named persons and others at these organizations have greatly enhanced this study.



#### TABLE OF CONTENTS

				Page
FRON	Tispi	ECE		
SUMM	ARY			i
ACKN	OWLED	GEMENTS		iii
TABL	E OF	CONTENT	S	iv
LIST	OF F	IGURES		vi
LIST	OF T	ABLES		ix
1.0	INTR	ODUCTIO	N	1
			Background	2
	1.2		ns for Nuclear Electric Rocket	•
	1.3	Overal	led Spacecraft l Study Approach	3 5 6
			Guidelines	6
2.0	TECH	NICAL D	ISCUSSION	8
	2.1	Task 1	- Power System Conceptual Design Studies	8
		2.1.1	Study Method	8
		2.1.2	Reference System Design at 400 kWe	12
			Preliminary Conceptual Design at 100 kWe Analytical Results from 100- to 1000-kWe Studies With Near-Term and Obtainable	14
			Brayton Technologies	16
	2.2	Task 2	- Primary Radiator Conceptual Design	28
		2.2.1	Configuration Studies	26
			Meteoroid Protection	30
			Analytical Design	32
			Heat-Pipe Data	34
		2.2.3	Advanced Heat-Pipe Concepts	35
	2.3		- Reference System Configuration and	
		_	ent Conceptual Design	35
			Reference System Configuration	35
		2.3.2	Nuclear Subsystem	37
			Reactors Radiation Shields	41
		2.3.3	Heat Source Heat Exchanger	48 48
			Combined Rotating Unit	50
			Recuperator	53
			Heat-Pipe Radiator Design	55
			Power Conditioning and Associated	
			Heat Rejection	61



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A RIVISION OF THE SAMETIC COMPONIATION

#### TABLE OF CONTENTS (Contd)

			Page
3.0	CONC	LUSIONS	62
4.0	RECO	MMENDED FURTHER STUDIES AND ANALYSES	64
	4.1	Refined System Designs, Including Reliability -	
		Life Characteristics	64
	4.2	Advanced Component Designs	65
	4.3	Space Radiator Designs with Advanced Heat Pipes	65
	4.4	System Operations, Especially Safety	65
	4.5	Probability of Mission Success	66
		Cost and Other Economic Analyses, Including Risk	66
	4.7		66
5.0	RECO	MMENDED TECHNOLOGY EFFORTS	67
	5.1	100-kWe System Technology	69
	5.2	400-kWe System Technology	72
		1000-kWe System Technology	74
6.0	REFE	RENCES	76

#### **APPENDICES**

- A THERMACORE HEAT-PIPE DATA (52 Pages)
- B LASL PEACTOR DATA (36 Pages)

#### LIST OF FIGURES

Figure No.		Page No.
Frontispiece	Nuclear Reactor Brayton Electric Spacecraft in Orbit About Io	
1	Net Spacecraft Mass in Jupiter Orbit Vs Time of Flight	4
2	Brayton Space Power System Design Methodology	11
3	Nuclear Electric Spacecraft Design with a 400-kWe Brayton Power System	13
4	Preliminary 100-kWe Nuclear Electric Spacecraft Design with a 400-kWe Brayton Power System	15
5	Specific Mass Vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Jovian Environment	17
6	Specific Radiator Area Vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Jovian Environment	18
7	Specific Mass Vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Near-Earth Environment	19
8	Specific Radiator Area Vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Near Earth-Environment	20
9	Specific Mass Vs Overall System Efficiency of 100-kWe System at a Turbine Inlet Temperature of 1325°K (1925°F) in a Near-Earth Environment	21
10	Specific Radiator Area Vs Overall System Efficiency of 100-kWe System at a Turbine Inlet Temperature of 1325°K (1925°F) in a Near-Earth Environment	22
11	Specific Mass Vs Overall System Efficiency of 1000-kWe System at a Turbine Inlet Temperature of 1650°K (2510°F) in a Jovian Environment	23
	or roso v (saro e) in a novial plivifalidele	<b>4.</b> 3

#### LIST OF FIGURES (Contd)

Figure No.		Page No.
12	Specific Radiator Area Vs Overall System Efficiency of 1000-kWe System at a Turbine Inlet Temperature of 1650°K (2510°F) in a Jovian Environment	24
13	Conceptual Primary Radiator Designs	29
14	Meteoroid Protection Criteria	31
15	Radiator Design Method	33
16	Configuration of 400-kWe Brayton Power System for a Nuclear Electric Spacecraft	36
17	Nuclear Electric Spacecraft Dual Brayton Power Systems Schematic	38
18	400-kWe Reference Power System Brayton Cycle State Point	39
19	Space Nuclear Subsystem Reference Configuration	40
20	Relation of Heat Pipe Cooled Reactor Characteristics to Nuclear Subsystem Characteristics	41
21	LASL Reference Reactor Design Concept - 1650-kWt (Nominal)	44
22	LASL Reference Reactor Design Concept - 400-kWt (Nominal)	46
23	LASL Layered Core Heat Pipe Cooled Space Power Reactor Design Concept - 1200 kWt	47
24	Heat Source Heat Exchanger Concept and Characteristics	49
25	Combined Rotating Unit	51
26	Recuperator Design Concept and Characteristics	54
27	Heat Balance for & 400-kWe Brayton Power System	56
28	Cylindrical Heat Pipe Radiator Conceptual Design	57
29	Heat Pipe Radiator Heat Exchanger Design Concept and Characteristics	59



#### LIST OF FIGURES (Contd)

Figure No.		Page No.
30	Prospective Nuclear Spacecraft Power Requirements Vs Technology Readiness	68
31	Schedule of Key Power Conversion Technology Elements Required for Reactor/Brayton Space Power Systems	70



### 

#### LIST OF TABLES

Table No.		Page No.
1	Initial Brayton Power System Study Parameters	9
2	Summary of Selected Brayton System Designs	27
3	The Effect of Non-Puncture Probability on Armor Thickness	30
4	LASL Reference Reactor Characteristics -1650 kW <sub>t</sub> (Nominal)	43
5	LASL Reference Reactor Characteristics -400 kW <sub>t</sub> (Nominal)	44
6	Turbine and Compressor Wheel Characteristics	52
7	Mass Summary for Primary Radiator with Dual-Diameter Heat Pipes	60



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A SIMISSION OF THE SARREST CORPORATION PHOENIX, ARIZONA

#### STUDY OF REACTOR BRAYTON POWER SYSTEMS FOR NUCLEAR ELECTRIC SPACECRAFT

#### 1.0 INTRODUCTION

Studies are currently underway at the Jet Propulsion Laboratory (JPL) and at the Los Alamos Scientific Laboratory (LASL) to demonstrate the technical feasibility of nuclear reactor-powered spacecraft propelled by electric rocket thrusters. Such vehicles would be capable of performing detailed explorations of the solar system including rapid trips to the outer planets with massive payloads during the 1990s and into the 21st century. Particular emphasis has been placed on the definition of and on technology development for the power conversion subsystem with thermionics currently receiving primary attention.

The purpose of this study is to provide comparative information on an alternative conversion system, the Closed Brayton power system, to allow meaningful comparisons.

As a result of the large technological data base available from the development of numerous gas turbines as well as the significant R&D funding on Closed Brayton Cycle (CBC) engines over the past ten years, such engines should be considered an available technology with excellent potential for future development. Major questions to be resolved include definition of optimum operating parameters and effective integration with spacecraft elements including the launch vehicle, the nuclear subsystem (reactor and shield), the waste heat rejection system, and the space science payload. These topics are addressed in the three tasks that have been defined for this study, as described in Section 2.0. Estimation of system reliability and lifetime characteristics is of great interest, but could only be addressed

### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARREST COMPONIES PHOENIX, ARIZONA

in a very preliminary way within the confines of this study. The remainder of this introduction provides additional definition of the requirements for the Nuclear Electric Spacecraft.

#### 1.1 Study Background

Since the 1950s, the limitations of chemical rockets for extensive exploration of the solar system and other high-energy missions have been well understood. Electric-rocket propulsion was given considerable analytical and development attention during the past two decades and space flight tests were conducted. In comparison studies, nuclear electric rocket propulsion was repeatedly shown to be performance and economically effective for the more demanding missions when they would be flown.

In the early 1970s, the post-Apollo emphasis on Earth applications and, especially, the development of the Space Shuttle ransportation system caused space program planners to terminate all work on nuclear systems except for radioisotope thermoelectric generators (RTGs), some advanced reactor concepts, and compatible power conversion research.

During the past several years, projections of future space mission requirements, both military and civil, have resulted in a renewed interest in advanced nuclear systems. The Department of Energy (DOE) has technology development programs in advanced nuclear energy sources for space at LASL. The NASA Office of Aeronautics and Space Technology (OAST) Space Power and Electric Propulsion Division is funding power conversion technology developments, primarily in thermionics and thermoelectrics. Although Brayton power conversion in space has a history of over 20 years, the present study represents the first effort in recent years to assiss the component and system aspects in some detail using both available and obtainable technology. In particular, this study addresses the critical issue of space environment



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARRETT CORPORATION PHODENIX, ARIZONA

compatible radiator design which has been recognized for some time as the major drawback to application of CBC technology.

#### 1.2 Missions for Nuclear Electric Rocket Propelled Spacecraft

The primary missions identified by JPL for this study are solar system exploration of the outer planets with massive payloads. Figure 1 shows the net\* 400-kW nuclear electric, rocket propelled spacecraft mass versus time of flight for various thruster exhaust Two cases are shown with different masses of shielding for the nuclear reactor. The required shielding mass is probably between these cases. Performance is also shown for a 60-kW solarelectric rocket-propelled spacecraft. As can be seen, substantial masses can be placed in Jupiter orbit(1) \*\* which would represent a likely first use for the nuclear electric spacecraft. Reference 1 also contains data on flights to other outer planets and on a solar escape mission with high net mass and reasonable trip times. trajectory optimization of these and other high-energy missions are expected to result in a strong recommendation for the development of nuclear electric rocket propulsion capability.

In a more recent paper (2), Phillips and Pawlik discuss the design of a nuclear electric propulsion system, including the selection of thrusters and propellant for outer planet (Saturn, Uranus and Neptune) exploration. A power level between 200 and 250 kW $_{\rm e}$  is recommended with current technology for the early missions and growth potential for more difficult later missions. These missions could be accommodated without significant changes in the basic nuclear reactor heat source and heat rejection system.

<sup>\*</sup>Total spacecraft mass less the following term for Cases A and B--(1.03 propulsion system mass plus shielding mass).



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA

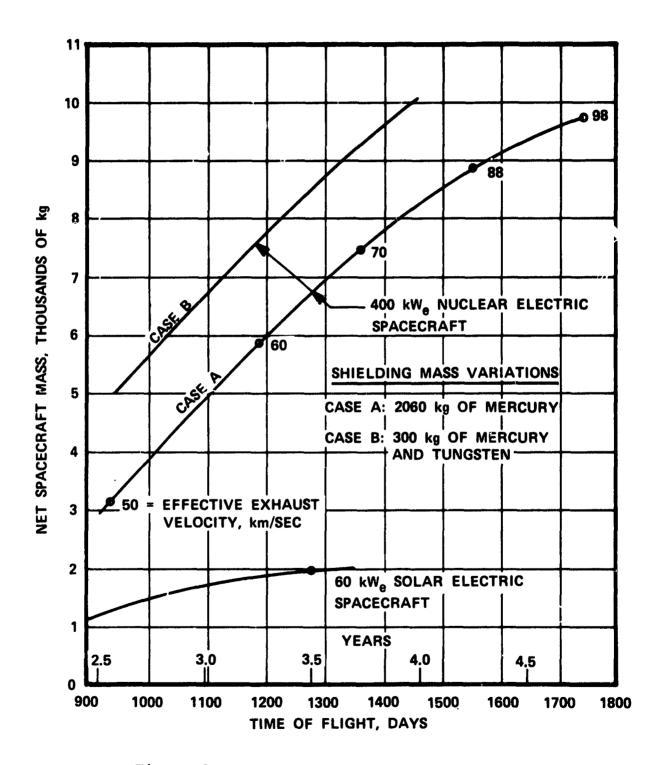


Figure 1. Net Spacecraft Mass in Jupiter Orbit Vs Time of Flight.



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A SIVISION OF THE SAMELY COMPANY OF ARIZONA PHOENIX, ARIZONA

Other high-energy missions in the 1990s and beyond will include such candidates as orbital transfer vehicles, both in geocentric orbits and throughout cislunar space, highly maneuverable military spacecraft, and the initial versions of solar system cruisers.

#### 1.3 Overall Study Approach

The study of CBC systems depends on the use of computer-based analytical methods. Only with such methods can thousands of candidate systems be designed and evaluated parametrically. A computer model based on appropriate guidelines and constraints has been created showing the variables intrinsic to CBC systems to be studied. The guidelines for the model are discussed in Section 1.4. The computer study method is described in Section 2.1.1.

A reference system design at 400 kW $_{\rm e}$  was evaluated in substantial detail and is discussed at some length in Section 2.1.2. Because of prospective interest in lower power systems, a preliminary layout of a  $100-{\rm kW}_{\rm e}$  system was prepared and is shown in Section 2.1.3. Analytical results for systems from 100 to 1000 kW $_{\rm e}$  using near-term and obtainable Brayton technologies are given in Section 2.1.4.

The major technical challenge of this study was the identification of a credible heat-pipe radiator. Early in the study, the Brayton power conversion system design parameters were selected from computer results which did not include all system components and which included a liquid-cooled radiator. A heat-pipe radiator was then designed using a separate radiator computer program and the mass adjusted accordingly. In the latter phase of the study, these computer models were merged and analytical representations of all system components were included. Achievement of this overall design tool is a major accomplishment of this study. Throughout this investigation, layouts of radiators were made and evaluated against two constraints—reasonable mass and ability to fit into the Space Shuttle bay.

### PARMSTY)

### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA

Specific heat-pipe designs were evaluated by Thermacore, Inc. under a JPL contract. The study results are discussed in Section 2.2.4 and presented in toto in Appendix A. The radiator geometry is discussed in greater detail in Section 2.3.

#### 1.4 Study Guidelines

There were two primary goals of this study--first, to study nuclear electric propulsion (NEP) power systems from 100 to 1000 kW $_{\rm e}$ , and second, to create a r ference design including a system layout at 400 kW $_{\rm e}$ . The following constraints and guidelines were given in the JPL contract (3) o. were expressed as highly desirable by JPL representatives:

- (a) The system should be designed for technology attainable in the 1985 to 1990 time frame.
- (b) The system must produce the voltage level desired by the ion thrusters.
- (c) System components must be placed within the shadow of the reactor shield.
- (d) The  $400-kW_e$  system and payload should fit within the Space Shuttle bay.
- (e) These systems should be designed to operate in a recently defined Jovian micrometeoroid environment throughout the mission life.
- (f) System lifetime is 120,000 hours.
- (g) The system specific mass at 400 kW $_{\rm e}$  should be less than 20 kg/kW $_{\rm e}$ .



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A BIVISION OF THE BARRETT COMPANION PHODENIX, ARIZONA

The following additional guidelines were assumed by AiResearch:

- (a) No single-point failures are allowed; hence, all systems include the mass of a redundant system.
- (b) The  $100-kW_e$  system would use essentially state of the art technology.
- (c) The 400- and 1000-kW<sub>e</sub> systems can utilize longer term technology.
- (d) Turbomachinery design is current state of the art.

### -----

### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARREY SERVICES PHOENIX, ARIZONA

#### 2.0 TECHNICAL DISCUSSION

#### 2.1 Task 1 - Power System Conceptual Design Studies

The method and the results of the study of power systems between 100 and '300 kW $_{\rm e}$  are described in the following sections. Conceptual designs at 400 and 100 kW $_{\rm e}$  are presented in greater detail.

#### 2.1.1 Study Method

The CBC computer design program was used to design thousands of candidate systems. This program requires input of key thermodynamic parameters to begin the cycle design. The output is complete preliminary design of the resultant systems, including masses of all components in both tabular and plotted forms. These systems are examined in detail and a reference system is selected. From the geometry of the components, a layout of the selected design can be made.

Table 1 lists the array of parameters that were studied. The most significant parameter is power level because system mass is a strong function of power level. The TIT and cycle temperature ratio\* are the next most important parameters. The cycle temperature ratio dictates the cycle efficiency (from the Carnot efficiency equation) depending upon the other parameters selected. TIT coupled with the cycle temperature ratio affects radiator size. The compressor specific speed, rotor speed, and power level determine the performance level of the turbomachinery and system pressure level. Rotor speed also determines the mass of the turbomachinery. Recuperator effectiveness affects thermal input, the mass of the recuperator, and radiator size. The pressure loss parameter has a strong effect on the

<sup>\*</sup>Ratio of compressor inlet temperature (CIT) to TIT.

#### 

TABLE 1
INITIAL BRAYTON POWER SYSTEM STUDY PARAMETERS

	Units	Values			
Net Output Power Level	kW <sub>e</sub>	100	400	1000	
Turbine Inlet Temperature	°K	1150	1325	1500	1650
Cycle Temperature Ratio (CIT/TIT)		0.25	to 0.40		
Compressor Specific Speed		0.07	to 0.15		
Rotating Speed	krpm	12 to	48		
Recuperator Effectiveness		0.88	to 0.97		
Pressure Loss Parameter		0.92			



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SAMELY COMPANY OF ARIZONA PHOENIX, ARIZONA

mass of the heat exchangers and system performance. The value that was selected (0.92) allows good system performance and reasonable heat exchanger mass.

Other variables that affect system mass include compressor pressure ratio, heat exchanger pressure drop, radiator sink temperature, and meteoroid flux. Compressor pressure ratio is selected to yield maximum system performance. Heat exchanger pressure drops are split between the heat exchangers for minimum system mass. Reactor thermal power affects both reactor and shield mass. The meteoroid flux can drastically affect radiator mass. All of these parameters are modeled in the computer code.

The compute: program is a series of overlay programs, i.e., all of the thermodynamic cycles are defined first; then, the recuperator for each cycle is designed, next the radiator for each cycle is designed, etc. Finally, these results are matched, listed, and plotted. Figure 2 shows the manner in which information is transferred between these programs.

The first and most important step is the cycle analysis. This program uses the input parameters shown in Table 1. Some other secondary inputs, such as alternator design characteristics, are also This program, based on empirical performance maps of the compressor and turbine, will design a thermodynamic cycle for a given combination of the above parameters. Among the information defined is compressor and turbine efficiencies and sizes, alternator windage and size, cycle efficiency, and the thermodynamic state points. From the thermodynamic state point and rotor size, the rotating unit mass is This design point information is stored on the computer calculated. The program continues to design cycles until all combinations disk. of parameters are exhausted.

PHOENIX, ARIZONA

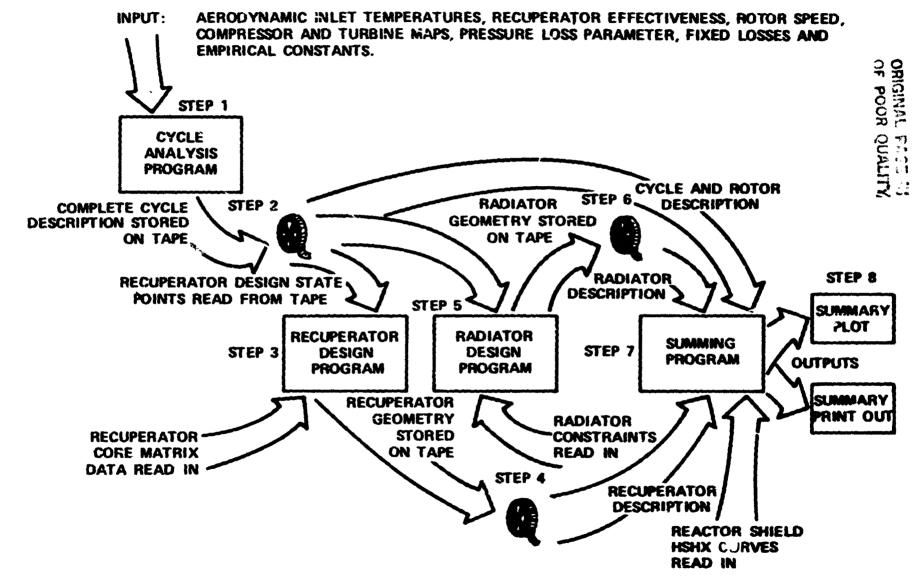


Figure 2. Brayton Space Power System Design Methodology



The next step is the design of the recuperator. The recuperator core matrix and other minor inputs are read in. Next, the cycle state point data are read from the computer disk. The recuperator is designed, and its mass and geometry are stored on the computer disk. After all of the recuperators are designed, the radiator design begins.

The heat-pipe radiator design program was added as a program option during this study. The calculation method is discussed in Section 2.3.6 (Radiator Conceptual Design). Like the recuperator program, it requires some basic input such as heat-pipe diameter, spacing, and length; gas heat exchanger data; micrometeoroid model; etc. It also uses the cycle state point data to design a heat-pipe radiator. The dimensions and mass of each radiator are stored on the computer disk. After a heat pipe radiator has been designed for each cycle, the calculation proceeds to the summing program.

In the summing program, the information stored on the computer disk is merged to form a complete system description. The mass of the remaining system components is calculated as a function of the appropriate cycle variables. Examples are duct mass, reactor mass, shield mass, and insulation mass. After the mass of every component is defined, the total system mass, system specific mass, and specific radiator mea are calculated. An abbreviated cycle description is printed, and the specific mass and area are plotted. The plots are shown and discussed in Section 2.1.4. When a candidate system is selected, an option that prints the geometry and performance of all of the components is used. From this geometry, a system layout can be made.

#### 2.1.2 Reference System Design at 400 kW

The  $400-kW_e$  system is illustrated in Figure 3. This configuration uses technology expected to be available at least by 1990 and is

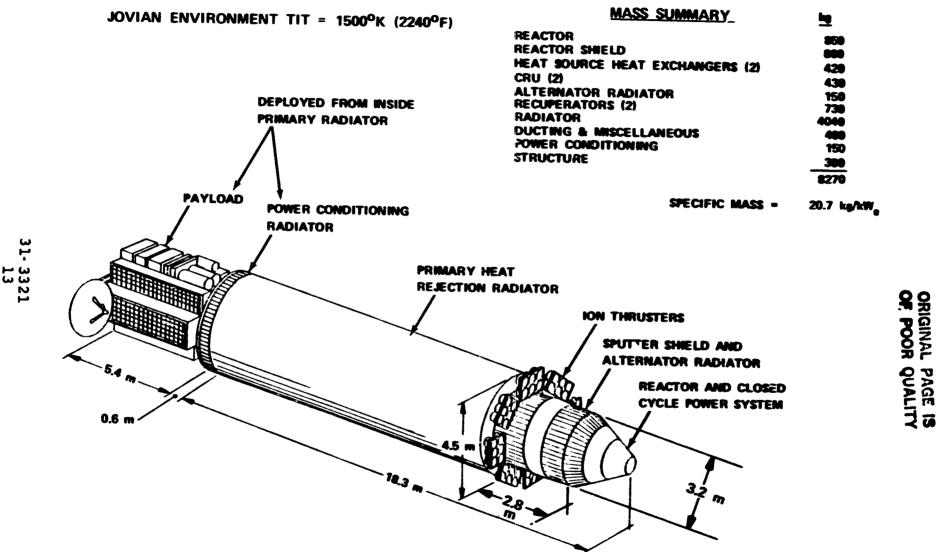


Figure 3. Nuclear Electric Spacecraft Design with a 400-kWe Brayton Power System



designed for operation near Jupiter. The largest and most noticeable component is the primary heat rejection radiator. Because this entire system must fit into the Space Shuttle bay, the radiator length was selected with care.

The spacecraft is located forward of all other components. To fit the payload bay envelope, several components are deployed after the unit is released from the Shuttle. The spacecraf' and power-conditioning radiator both telescope from inside the primary heat rejection radiator (this is also a feature of the baseline thermionic system). The ion thruster panels are rotated to a position normal to the axis of the spacecraft.

At the aft end of the spacecraft are the reactor and closed cycle power conversion systems. The reactor is the rearmost component. Inside the sputter shield and alternator radiator are the dual rotating groups, recuperators, and heat source heat exchangers. This configuration is simple and very compact.

Figure 3 shows that the specific mass is 20.7 kg/kW<sub>e</sub> With further refinement, the system specific mass could be decreased to meet or be less than the 20 kg/kW<sub>e</sub> design goal. For example, relaxation of the micrometeoroid environment to reflect the relatively low fraction of the mission duration spent close to Jupiter would result in the goal being surpassed without further refinement. More complete detail on this system is given in Section 2.3.

#### 2.1.3 Preliminary Conceptual Design at 100 kW

The 100-kW<sub>e</sub> conceptual design was studied in a very cursory fashion near the end of the study because of indications of early mission interest in this power level. Figure 4 shows the power system applied to a large telescoping and deploying space antenna. This

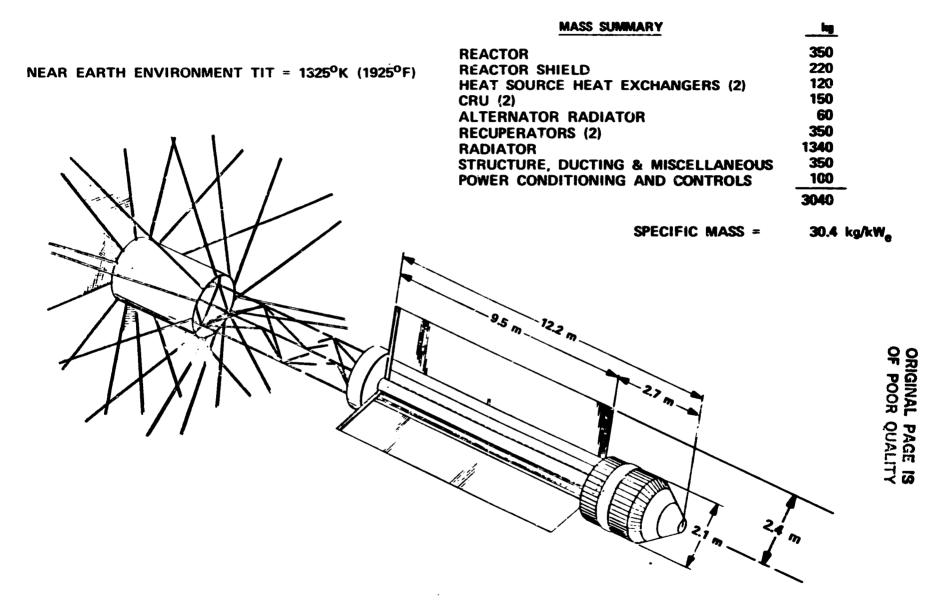


Figure 4. Preliminary 100-kWe Nuclear Electric Spacecraft Design

### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A BIVISION BY THE MARRETT COMPURATION PHOTONIC, ARIZONA

power system configuration will fit easily into the Space Shuttle payload bay. The component arrangement is generally similar to the 400-kWe system described previously. The mass summary given in Figure 4 reflects a conservative design based essentially on currently available technology. Two completely independent systems provide propulsion power so that no single-point failure can jeopardize a mission. Although the radiator is "Y" shaped, a cylindrical radiator could also be used which would be more compact but more massive.

The specific mass of  $30.4~kg/kW_e$  could quite clearly be significantly reduced by the use of more advanced technology (higher TIT). Even at the lower TIT, appreciable reduction could be achieved with further refinement. Unfortunately, such refinement was not possible within the resources available for this study.

### 2.1.4 Analytical Results from 100- to 1000-kW Studies with Near-Term and Obtainable Brayton Technologies

Figures 5 through 12 are "shotgun" plots generated by the previously described method (Section 2.1.1). Representative plots are included for three output powers (100, 400, and 1000 kW<sub>e</sub>). These plots are presented as representative examples of the analytical approach but do not reflect a significant improvement (use of dual diameter or necked heat pipes), which was made relatively late in the study. The effects of this improvement are described later in this section. Each point on these plots represents a specific system design according to the parameters of Table 1. Each set of results consists of separate plots of specific mass and specific radiator area. The specific mass includes the heat source, two completely redundant loops for all the power conversion components, the waste heat radiator, and required power conditioning components.

Flots of the  $400-kW_e$  system, designed for a 1995 flight with a  $1500^{\circ}K$  (2240°F) TIT are shown in Figures 5 through 8. A five-year



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A SIVISION OF THE SARRETT CORPORATION PHODENIA, ARIZONA

ORIGINAL PAGE IS OF POOR QUALITY

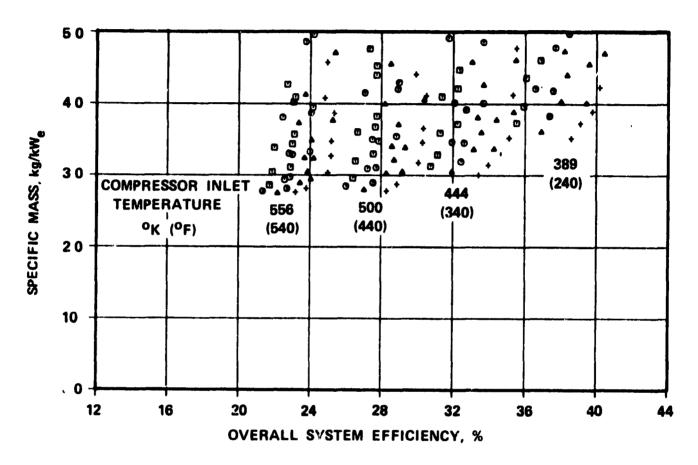


Figure 5. Specific Mass vs Overall System Efficiency of 400-kW<sub>e</sub> System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Jovian Environment



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A SIMISION OF THE MARRETT CORPORATION PHODRIN, ARIZONA

ORIGINAL FALLS IS OF POOR QUALITY

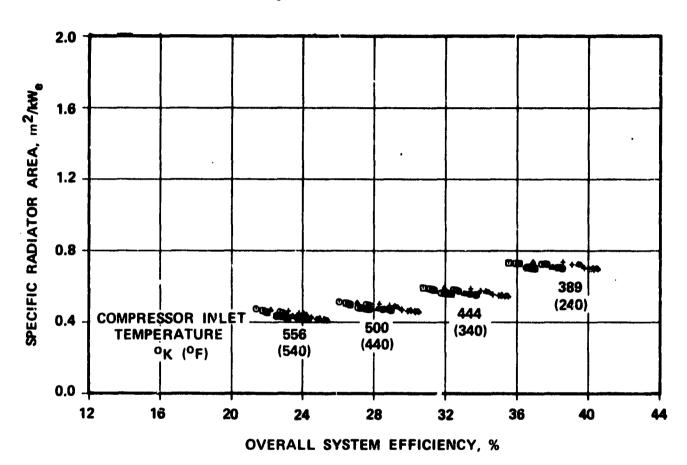


Figure 6. Specific Radiator Area vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Jovian Environment



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARETY SOSPORATION PHOENIX, ARIZONA

ORIGINAL PAGE IS OF POOR QUALITY

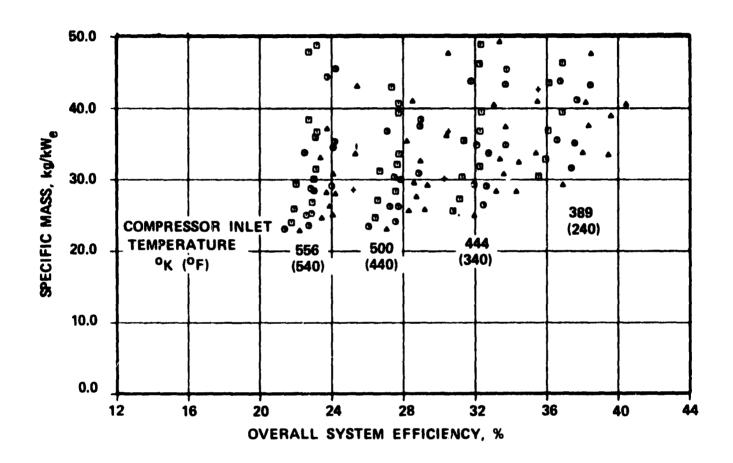


Figure 7. Specific Mass vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Near-Earth Environment



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA \* BIVISION OF THE SAMETIC COMPANY OF ARIZONA PHODENIX, ARIZONA

ORIGINAL PAGE IS OF POOR QUALITY

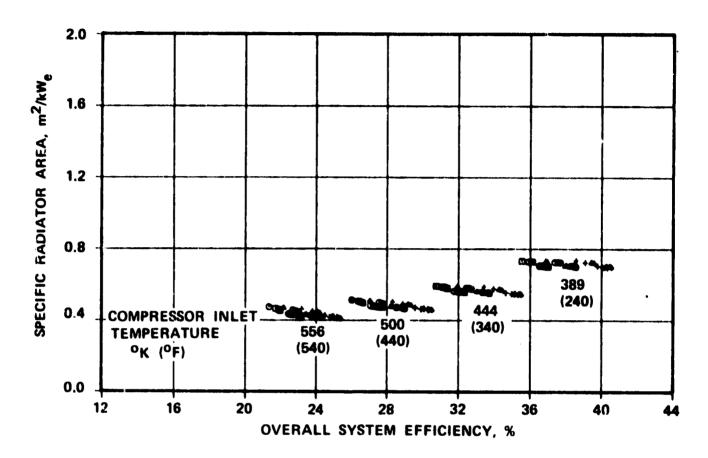


Figure 8. Specific Radiator Area vs Overall System Efficiency of 400-kWe System at a Turbine Inlet Temperature of 1500°K (2240°F) in a Near Earth-Environment

### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT COMPANY OF ARIZONA PHOENIX, ARIZONA

ORIGINAL ( ACC

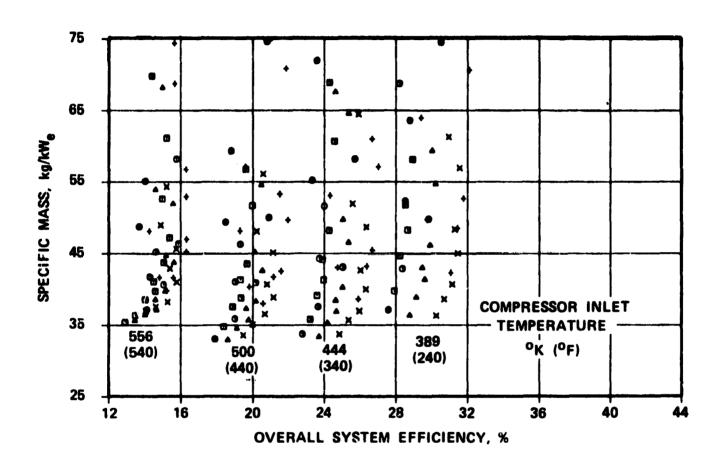


Figure 9. Specific Mass vs Overall System Efficiency of 100-kW System at a Turbine Inlet Temperature of 1325°K (1925°F) in a Near-Earth Environment



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A RIVISION OF THE SAMELITE COMPANY OF ARIZONA PHOENIX, ARIZONA

ORIGINAL PROTEIN OF POUL QUALITY

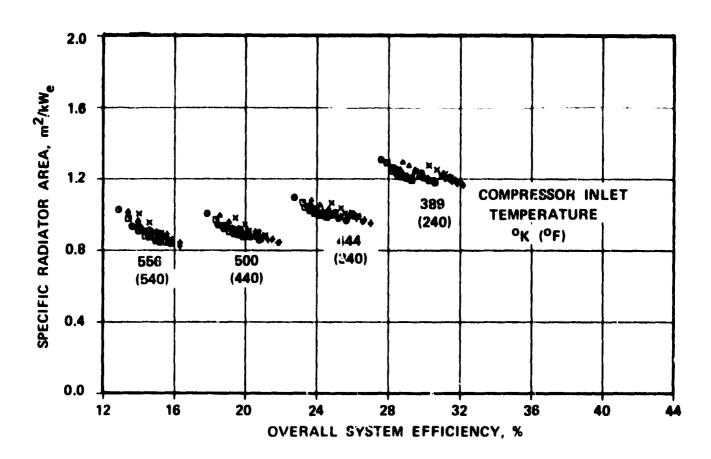


Figure 10. Specific Radiator Area vs Overall System Efficiency of 100-kWe System at a Turbine Inlet Temperature of 1325°K (1925°F) in a Near-Earth Environment



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA PHOENIX, ARIZONA

ORIGINAL FRAL IS

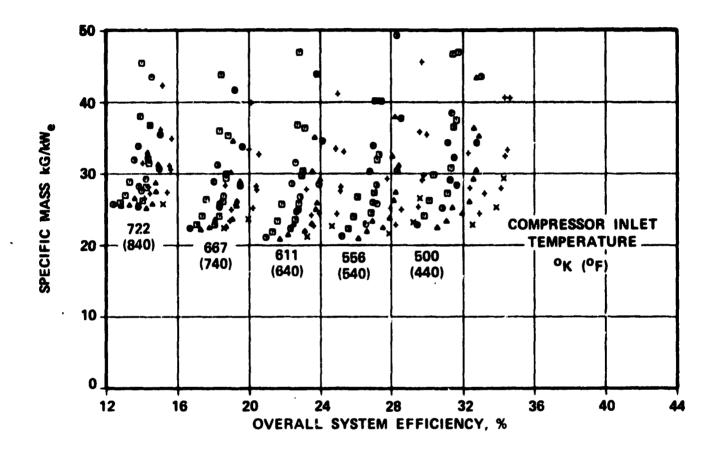


Figure 11. Specific Mass vs Overall System Efficiency of 1000-kW<sub>e</sub> System at a Turbine Inlet Temperature of 1650°K (2510°F) in a Jovian Environment

# AFRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SAMPLES COMPANY OF ARIZONA PHOENIX, ARIZONA

ORIGINAL PAGE IS OF POOR QUALITY

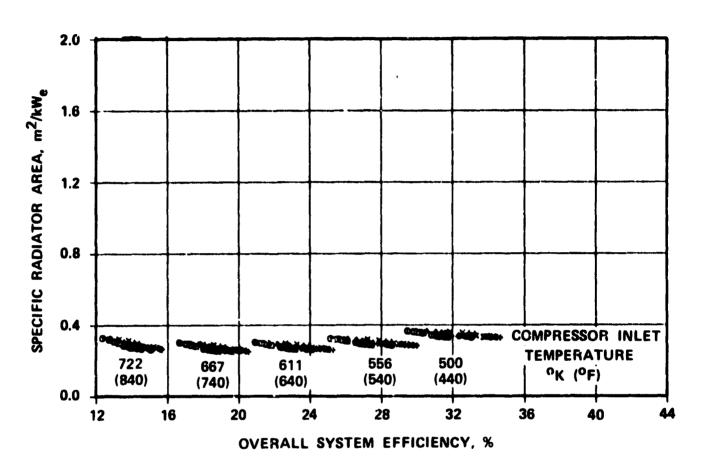


Figure 12. Specific Radiator Area vs Overall System Efficiency of 1000-kWe System at a Turbine Inlet Temperature of 1650°K (2510°F) in a Jovian Environment

### 

flight system development is assumed with the result that this TIT, which can be attained with high-strength refractory materials, should be state-of-the-art by 1990. The inferences of this technology development schedule are discussed subsequently. The waste heat radiators for these systems employ the fixed cylindrical geometry shown in Figure 3. Previously, a hinged, three-panel design had been considered that was somewhat less massive but required in-space assembly operations (automated welding or brazing at the 400-kW<sub>e</sub> power level. Comparison of the specific mass data for the Jovian (Figure 5) and near-Earth (Figure 7) environments shows the substantial effect of the meteoroid armor requirement. These systems have masses that are well within the capability of a single Shuttle launch and dimensions that fit within the payload bay.

Figures 9 and 10 show the specific mass and specific radiator area for 100-kW<sub>e</sub> systems designed for the near-Earth micrometeoroid environment and for a TIT of 1325°K (1925°F). These systems would be based on essentially existing technology (mostly superalloy with some well-characterized refractory hot section components) which results in relatively large masses and radiator areas. The system configuration with a three-panel radiator is shown previously in Figure 4 and fits easily within the Shuttle payload envelope.

The specific mass and radiator areas characteristic for 1000-kWe systems are shown in Figures 11 and 12. The TIT for these systems, 1650°K (2510°F), is commensurate with ceramic technology which should be available by 1995 (yielding a projected operational date of 2000). Specific mass and radiator area are the lowest of all the systems analyzed, illustrating most significantly the payoff of advanced technology. As a result of a number of on-going programs (four to six), AiResearch concludes that the ceramic technology will be available as outlined above. Indeed, these time frame projections may be conservative rather than optimistic.



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

Table 2 shows the effect of environment, power level, and turbine inlet temperature on specific mass and radiator area. The table lists the specific radiator area of the system that has minimum specific mass. The table shows that both specific mass and radiator area decrease as power level and/or turbine inlet temperature increase. The requirement to operate in the Jovian environment has an adverse effect on system mass.

In Table 2, the values in the column labeled "Specific System Mass" were determined directly from the "shotgun" plots. As noted previously, the radiator is by far the most massive component in the power system. As described in Section 2.2.5, a modification to use "dual-diameter" heat pipes was defined late in the study. In this approach, a large diameter is used in the evaporator section to yield adequate heat transfer from the cycle working fluid and a smaller diameter is used for the condenser. This modification allowed the radiator to be redesigned for a much lower mass. Estimates were made of the reductions possible, and the resultant modifications to the specific mass are listed in the column labled "Specific System Mass with Refined Radiator". The plots may still be used to determine the relative merits of alternative system design points.

The most important parameter in Table 2 is the specific mass of the  $400\text{-kW}_{\rm e}$  system. For the Jovian environment, the specific mass is  $21~{\rm kg/kW}_{\rm e}$  which is within 5 percent of the design goal. With further refinement, this value could probably be made less massive than the goal.  $400~{\rm kW}_{\rm e}$  systems designed for the near-Earth environment are lighter than the design goal of  $20~{\rm kg/kW}_{\rm e}$ . The advanced  $1000\text{-kW}_{\rm e}$  system for Jovian environment has the highest performance of all with a specific mass of  $15~{\rm kg/kW}_{\rm e}$ .

# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

TABLE 2
SUMMARY OF SELECTED BRAYTON SYSTEM DESIGNS

Power Level kW <sub>e</sub>	Turbine Inlet Temperature °K	Environment	Specific System Mass kg/kW <sub>e</sub>	Specific System Mass With Refined Radiator kg/kWe	Specific Radiator Area m <sup>2</sup> /kW <sub>e</sub>
400	1500	Jovian	28	21	0.42
400	1500	Near-Earth	23	19	0.42
100	1325	Jovian	46	41	1.0
100	1325	Near-Earth	34	30	1.0
100	1500	Near-Earth	29	26	0.72
1000	1500	Jovian	26	20	0.38
1000	1650	Jovian	21	17	0.30
1000	1800	Jovian	18	15	0.25



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA

#### 2.2 Task 2 - Primary Radiator Conceptual Design

In this task, primary waste heat radiator layout studies were undertaken. An analytical model of the radiator was defined and used in Task 1 to create the designs. Finally, the radiator design was checked against the Thermacore heat-pipe data. The geometry of the radiator selected for the  $400-kW_{\rm e}$  system is discussed in Section 2.3.5 below.

### 2.2.1 Configuration Studies

The radiator configurations derived during the layout study are shown in Figure 13. There are four designs labeled (A) through (D).

All of these configurations are similar in their design approach. Each has a gas-to-heat-pipe heat exchanger where the heat is transferred to the evaporator section of the heat pipe. Each has a condensing section and fin from which the waste heat is radiated. Each has armor protection for the condenser section. Some radiate from only one side of the panel.

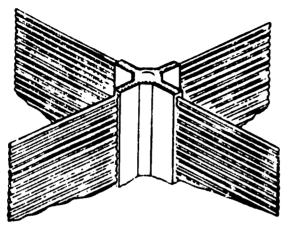
Configuration (A) is based on a LASL design approach. It has four heat-pipe panels with a cruciform gas to heat pipe heat exchanger. Inside the heat exchanger are small diameter tubes which are joined to the evaporator. These tubes carry the working fluid and provide additional heat transfer surface.

Configuration (B) has eight slightly curved panels which together make a right circular cylinder. Each panel has two gas-to-heat-pipe heat exchangers because these are two power conversion systems. Each gas heat exchanger is protected from meteoroid impact by the adjacent heat-pipe panels that overlap the heat exchangers.

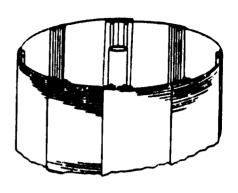


### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

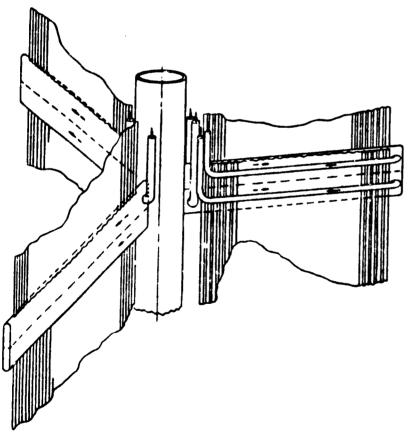
### ORIGINAL PAGE IS OF PUDR QUALITY



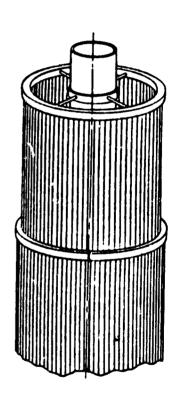
A. FOUR PANEL (LASL) DESIGN



B. CYLINDRICAL DESIGN



C. THREE PANEL DESIGN



D. CAMPING-CUP DESIGN

Figure 13. Conceptual Primary Radiator Designs

# AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT CORPORATION PHOENIX, ARIZONA

Configuration (C) is a three-panel design with axial heat pipes. There is a double heat exchanger located midway the axial length of the panel. This heat exchanger has heat pipes that exit from both the top and bottom.

The last radiator concept configuration (D), has a number of telescoping panels. The heat pipes are parallel to the axis of the radiator. The gas heat exchanger is located at the top of each panel. The major problem with this design is the flexible joints that must seal the working fluid loop.

For this study, configuration (B) was selected for the  $400\text{-kW}_{\text{e}}$  system. A combination of the features of (A) and (C) were used for the  $100\text{-kW}_{\text{e}}$  layout.

### 2.2.2 Meteoroid Protection

The armor thickness is based on the equation shown on Figure 14. This information was supplied by JPL and includes the effect of operation in the Jovian environment. The number of failures is based upon the binomial distribution. For this study, it was found advantageous to design for a high probability of non-puncture. Table 3 lists shows the effect of non-puncture probability on armor thickness.

TABLE 3

THE EFFECT OF NON-PUNCTURE PROBABILITY ON ARMOR THICKNESS

Probability of Non-puncture of An Individual Tube	Percentage of Tubes Not Punctured*	Armor Thickness Ratio
0.85	83.5	1.000
0.90	88.8	1.134
0.95	94.1	1.397
0.99	98.6	2.242

<sup>\*99</sup> percent probability that no more than this percentage of tubes will be punctured. The specific design for the  $400-kW_{\rm e}$  system was based on 95 percent non-puncture.

BASED ON PROTECTION FOR A SINGLE HEAT PIPE

$$t = C \left[\frac{AT}{-ln(P)}\right] 0.2902$$

WHERE

t IS ARMOR THICKNESS, cm

C IS 0.00110 FOR LOCKALLOY

A IS VULNERABLE AREA, cm<sup>2</sup>

T IS MISSION TIME, HOURS

P IS NO PENETRATION PROBABILITY

NUMBER OF HEAT PIPE FAILURES BASED ON BINOMIAL DISTRIBUTION

$$P(i) = \sum_{m=0}^{i} \frac{P^{m}(1-P)^{n-m} n!}{m! (n-m)!}$$

P(i) IS PROBABILITY OF i OR FEWER PUNCTURES (i  $\leq$  n)

n IS TOTAL NUMBER OF HEAT PIPES

m IS NUMBER OF FAILED HEAT PIPES

Figure 14. Meteoroid Protection Criteria



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARGETT CORPORATION PHOENIX, ARIZONA

It can be seen that increasing the non-puncture probability from 0.85 to 0.95 increases the armor thickness (and mass) by 40 percent. This is a worthwhile tradeoff when the major mass is the heat exchanger and heat pipes. If a low probability is selected, more heat pipes and heat exchanger mass must be added to compensate for the failed heat pipes. Excess heat transfer area on both the gas convection surface and the radiating surface will ensure that this radiator will function as designed when 6 percent of the tubes have failed.

#### 2.2.3 Analytical Design

Analysis of the radiator utilizes a computer program. This program has been integrated into the cycle design program so that radiators can be designed at the same time the thermodynamic cycle is derived. Figure 15 summarizes the design method. Input from the cycle design program constitutes the major variables, such as:

- o Heat rejection rate
- o Flow
- o Temperature
- o Fluid properties
- o Pressure drop

Other input, which applies to the particular configuration to be studied, is read by the radiator program. This input includes:

- o Heat pipe diameter and wall thickness
- o Condenser length
- o Gas heat exchanger width
- o Heat transfer data
- o Armor model

With this input, the gas heat exchanger size and radiating area are calculated. The frontal area of the heat exchanger (and therefore

A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA

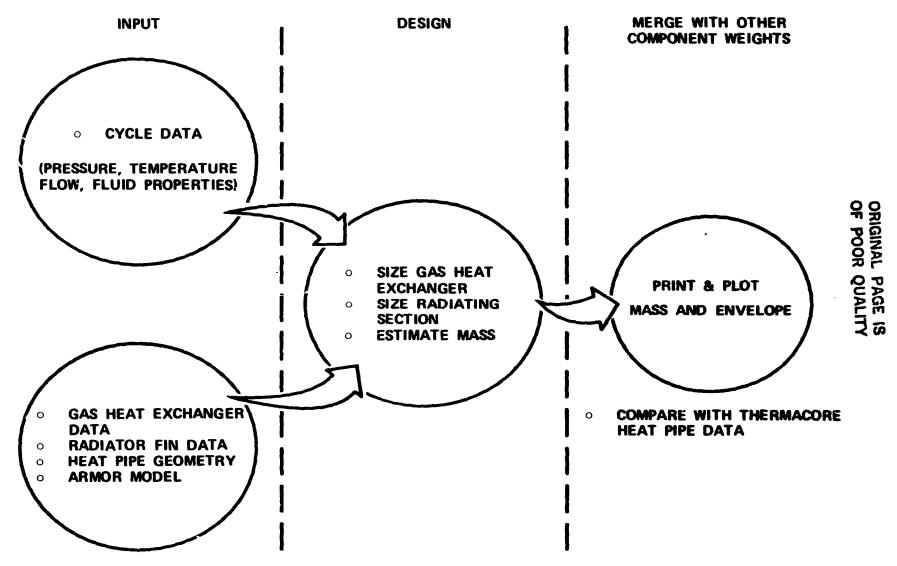


Figure 15. Radiator Design Method

1-332. 33



## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A BIVISION OF THE BARRETT CORPORATION PHODENIX, ARIZONA

the evaporator length) is a function of the pressure drop. The heat transfer conductance has a strong effect on radiator size. The computer program calculates the length of the heat exchanger based on the conductance and radiating temperature. Evaporator length is changed as necessary to satisfy pressure drop. The program iterates until both heat transfer and pressure drop requirements are satisfied simultaneously.

When the calculation has converged, the mass of the radiator is calculated. This mass includes heat pipes, fin, armor, two gas-to-heat-pipe heat exchangers, and associated heat exchanger components (wrapup, headers, duct extension, and flanges).

The last step is to compare the computer heat pipe results with data on specific designs supplied by Thermacore. If the result is favorable, the conceptual design is accepted. If not, iteration is required.

#### 2.2.4 Heat-Pipe Data

Appendix A includes the results of the Thermacore radiator heat pipe study (7). The important conclusions are:

- o Rubidium is the preferred working fluid for 1 in. OD heat pipes when the temperature is above 650°K (710°F).
- Mercury is acceptable for temperatures as low as 550°K (530°F) if the heat-pipe diameter is less than 1 in. In fact, the power transferring capability of the heat pipe increased as the diameter decreased.
- O Dowtherm A is the preferred fluid below 550°K (530°F) [minimum radiating surface temperature is 492°K (426°F)].
- Other advanced designs might offer increased performance and lower mass.

## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT COMPONISTION PHOENIX, ARIZONA

#### 2.2.5 Advanced Heat-Pipe Concep's

A comparison of the performance characteristics of the evaporator and consenser sections of constant diameter heat pipes led to the conclusion that this type of heat pipe was not the optimum design. Thermacore agreed that it was possible to design and build heat pipes in which the evaporator diameter is greater than the condenser diameter. This results in a heat-pipe radiator in which the evaporation area is sufficient for convective heat transfer from the gas working fluid, and the condenser section is operated somewhat closer to the maximum heat transfer capability. The smaller heat-pipe condenser section minimizes vulnerable area and heat-pipe mass; consequently, armor mass is also minimized. This design concept reduced the radiator mass of the 400-kW<sub>e</sub> reference system by 45 percent. Use of alternative advanced heat-pipe geometries may provide further substantial mass savings.

# 2.3 <u>Task 3, Reference System Configuration and Component Conceptual Design</u>

The overall reference system design concept is described in Section 2.1.3 above. The  $400\text{-kW}_{\text{e}}$  spacecraft design that will fit in the Space Shuttle orbiter payload bay is shown in Figure 3 with major elements identified. The mass summary discloses the radiator to be, by far, the major mass element of the 8270-kg total mass. Further refinement of this heat-pipe radiator design and of the other components will permit appreciable reduction in the specific mass of  $20.7 \text{ kg/kW}_{\text{e}}$ .

#### 2.3.1 Reference System Configuration

The configuration of the  $400-kW_{\rm e}$  Brayton power system is shown in Figure 16\* with the nuclear subsystem farthest aft, away from the

<sup>\*</sup>Approximate dimensions for the power conversion components may be scaled from the figure.

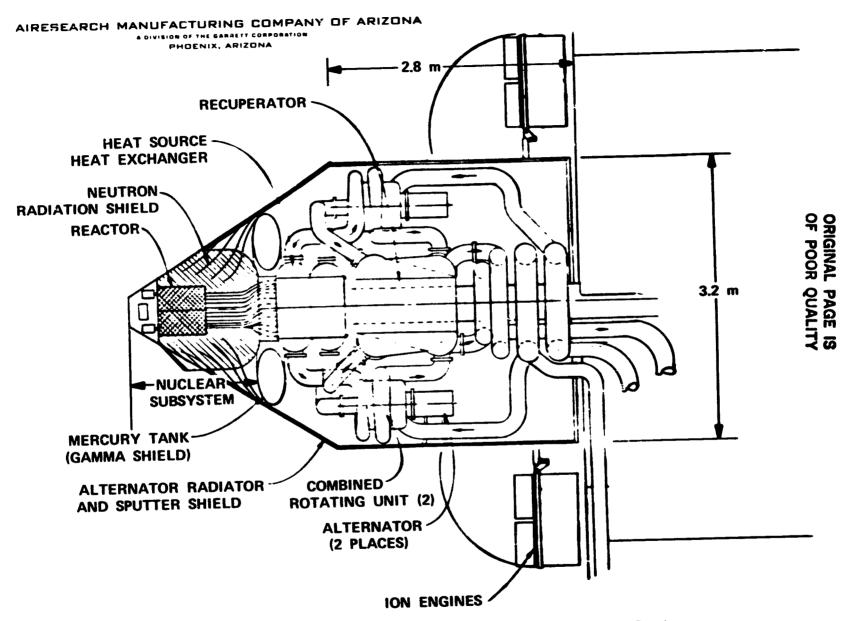


Figure 16. Configuration of 400-kW<sub>e</sub> Brayton Power System For a Nuclear Electric Spacecraft.



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARBETT CORPORATION PHOENIX, ARIZONA

spacecraft, and the compactly clustered components of the two power conversion systems next to the panel-mounted ion engines. The cylindrical radiator encloses the spacecraft during launch and, thus, is between the spacecraft and the power system in the deployed configuration.

A schematic of the dual Brayton power systems used to eliminate the single-point failure mode in the nuclear electric spacecraft is given in Figure 17. Both completely independent systems, each of which is capable of producing 400 kW<sub>e</sub>, are operated at half power under normal conditions. In the unlikely event that one of the systems becomes inoperable, the failed system is turned off and the pressure level doubled in the remaining system to restore full power output. Other means of assuring the required reliability for long durations are conceivable but the above method is preferred, at least until quantitative reliability and mass trade-off studies are accomplished.

Brayton cycle state points for the  $400-kW_e$  reference system are given in Figure 18. The reactor with an outlet temperature of  $1600\,^\circ\text{K}$  provides the thermal energy to the heat source heat exchanger that provides the temperature rise from 1114 to 1500 $^\circ\text{K}$ . The primary radiator provides the compressor inlet temperature of  $500\,^\circ\text{K}$ . The mass flow is 7.5 kg/sec.

#### 2.3.2 Nuclear Subsystem

The nuclear subsystem configuration is delineated in Figure 19. The two major components are the reactor and its lithium hydride neutron shield. Controls, insulation, shield cooling heat pipes and radiator, and the mercury propellant tank, which serves as a gamma shield, are also shown in the figure.



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

NOTE: DUAL FULL POWER CONVERSION SYSTEMS ARE COMPLETELY INDEPENDENT

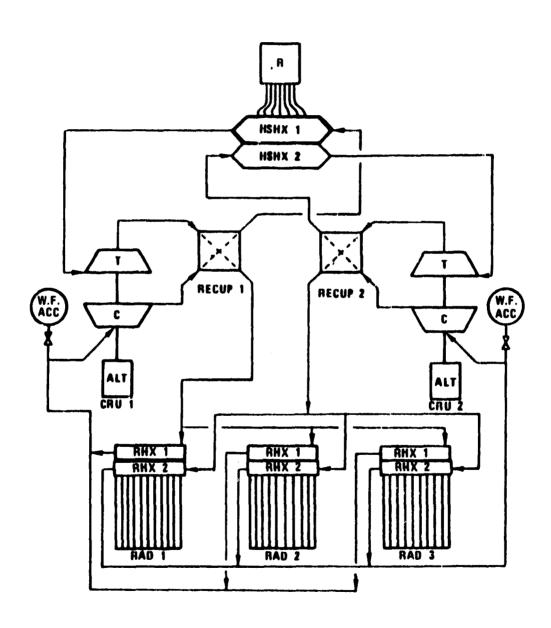


Figure 17. Nuclear Electric Spacecraft Dual Brayton Power Systems Schematic

### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

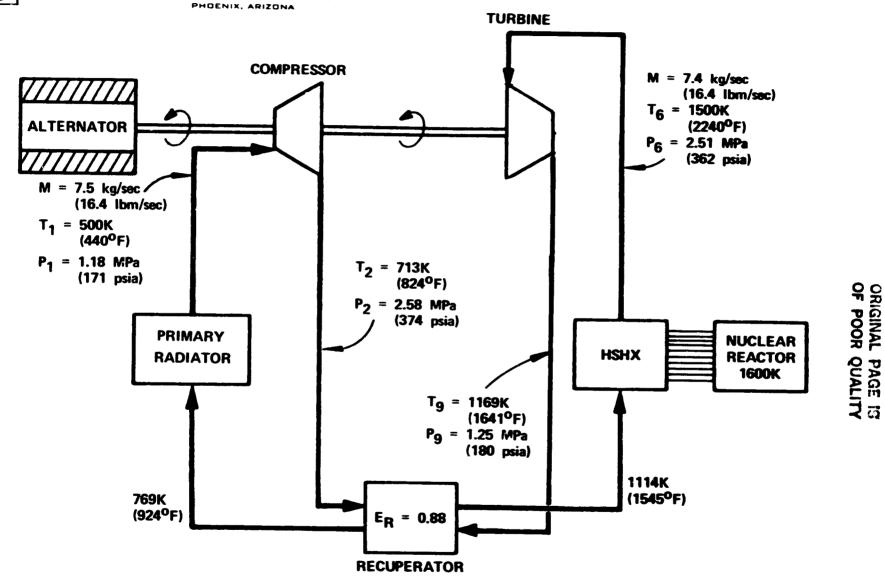


Figure 18. 400 kW<sub>e</sub> Reference Power System Brayton Cycle State Points

39 39

Figure 19. Space Nuclear Subsystem Reference Configuration

40



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA \* BIVISION OF THE SAMELY COMPANY OF ARIZONA PHOENIX, ARIZONA

The relation of heat-pipe cooled reactor characteristics to the characteristics of the nuclear subsystem are diagrammed in Figure 20. Preliminary determinations have been made of reactor and subsystem specific mass; the other characteristics remain for future analysis.

#### Reactors

LASL has provided parametric data on heat-pipe cooled reactors with uranium oxide (UO<sub>2</sub>) and uranium carbide (UC) fuels. These data (8,9) are included in Appendix B. Data were also provided on gas cooled reactors (10) but they have not been used in this study. Characteristics of the nominal 1650-kW<sub>t</sub> reactor selected for the 400-kW<sub>e</sub> reference power system are shown in Table 4. The hexagonal fuel elements are made from a 60% UO<sub>2</sub>-40% molybdenum mixture and have a central heat pipe for removing the thermal power. This reactor is a 0.6 m "square" cylinder with a total mass of 875 kg. The reactor specific mass is 0.53 kg/kW<sub>t</sub>. The design concept for this LASL reference reactor is shown in Figure 21.

Another reference reactor with  $400\text{-kW}_{\text{t}}$  nominal thermal power was identified for the preliminary conceptual design of the  $100\text{-kW}_{\text{e}}$  power system with the characteristics listed in Table 5. This reactor has Uranium carbide-Zirconium carbide fuel elements. It has a 0.24-m diameter and a 0.24-m length, and a mass of 346 kg so that the specific mass is 0.87 kg/kW<sub>t</sub>. The configuration of the  $400\text{-kW}_{\text{t}}$  reactor can be seen in Figure 22 to be similar to the  $1650\text{-kW}_{\text{t}}$  reactor.

LASL has recently published data on a new layered core heat-pipe cooled reactor design concept (11). The 1200-kW<sub>t</sub> thermal power version is shown in Figure 23. Data on these new reactors have been made available too recently to be incorporated in this study although the layered core offers many improved characteristics. The reactor mass at 1200 kW<sub>t</sub> is currently given as 470 kg for a specific mass of 0.39 kg/kW<sub>t</sub> which should result in considerably improved system parameters.

Figure 20. Relation of Heat Pipe Cooled Reactor Characteristics to Nuclear Subsystem Characteristics



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT CORPORATION

PHOENIX, ARIZONA

### TABLE 4

LASL REFERENCE REACTOR CHARACTERISTICS - 1650 kWt (nom.)

REACTOR TYPE	FAST SPECTRUM, HEAT PIPE COOLED
THERMAL POWER	1650 kW <sub>t</sub>
LIFETIME	87.6 X 10 <sup>3</sup> h
FUEL TYPE	UO2 - Mo (60%)
FUEL ELEMENT CLAD	Mo
HEAT PIPE WALL/WORKING FLUID	Mo/Li
NO. OF FUEL ELEMENTS (AND HEAT PIPES)	210
FUEL ELEMENT WIDTH (ACROSS HEX. FLATS)	0.0246 m
FUEL ELEMENT LENGTH	0.2756 m
MAXIMUM FUEL TEMPERATURE	1696 K
AVERAGE POWER IN FUEL SPACE	53 MW <sub>t</sub> /m <sup>3</sup>
FISSION DENSITY	4.968 X 10 <sup>20</sup> FISSIONS/cm <sup>3</sup>
FUEL SWELLING	1.11 VOLUME %
FUEL ( <sup>235</sup> U) BURNUP	4.6 ATOM %
CORE DIAMETER	0.3756 m
CORE LENGTH	0.3756 m
CORE VOLUME	0.042 m <sup>3</sup>
CORE VOID FRACTION	0.328
CORE POWER DENSITY	39.3 MW <sub>1</sub> /m <sup>3</sup>
REFLECTOR MATERIAL	Be, BeO
STRUCTURAL MATERIAL	Mo
REACTOR DIAMETER	0.6056 m
REACTOR HEIGHT	0.5856 m
REACTOR VOLUME	0.169 m <sup>3</sup>
READTOR POWER DENSITY	9.76 MW <sub>t</sub> /m <sup>3</sup>
REACTOR OUTLET (HEAT PIPE) TEMPERATURE	1600 K
REACTOR MASS SUMMARY, kg	1000 K
FUEL ( $^{235}$ U MASS = 150.6 kg)	
REFLECTOR	275
HEAT PIPES (112.24 kg/m)	322
CONTROL SYSTEM	166
SUPPORT STRUCTURE	33
	<u>57</u>
TCTAL MASS	875
REACTOR SPECIFIC MASS	0.530 kg/kWt



### ARESEARCH MANUFACTURING COMPANY OF ARIZONA

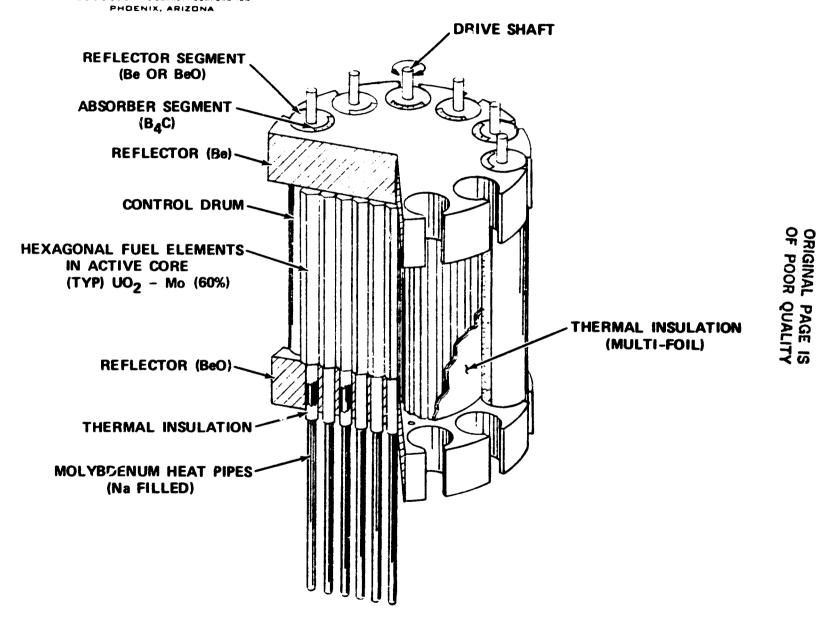


Figure 21. LASI Reference Reactor Design Concept - 1650 kW<sub>t</sub> (nom.)

#### TABLE 5

### LASL REFERENCE REACTOR CHARACTERISTICS - 400 kWt (nom.)

REACTOR TYPE FAST SPECTRUM, HEAT PIPE COOLED THERMAL POWER 400 kW, 87.6 X 10<sup>3</sup> h LIFETIME FUEL TYPE UC - ZrC FUEL ELEMENT CLAD Mo HEAT PIPE WALL/WORKING FLUID Mo/Li NO. OF FUEL ELEMENTS (AND HEAT PIPES) 84 FUEL ELEMENT WIDTH (ACROSS HEX FLATS) 0.0246 m FUEL ELEMENT LENGTH 0.2381 m MAXIMUM FUEL TEMPERATURE 1554.2 K AVERAGE POWER IN FUEL SPACE 47.83 MW<sub>\*</sub>/m<sup>3</sup> FISSION DENSITY 4.474 X 1020 Fissions/cm3 FUEL SWELLING 6.44 VOLUME % FUEL BURNUP 2.15 ATOM % **CORE DIAMETER** 0.2381 m CORE LENGTH 0.2381 m **CORE VOLUME** 0.0106 m **CORE VOID FRACTION** 0.3295 CORE POWER DENSITY 37.74 MW./m<sup>3</sup> REFLECTOR MATERIAL Be, Be? STRUCTURAL MATERIAL Mo REACTOR DIAMETER 0.4681 m REACTOR LENGTH 0.4481 m REACTOR VOLUME 0.0771 m REACTOR POWER DENSITY 5.188 MW<sub>\*</sub>/m<sup>3</sup> REACTOR OUTLEY (HEAT PIPE) TEMPERATURE 1425 K REACTOR MASS SUMMARY, kg FUEL (235 U MASS = 78.2) 92.0 REFLECTOR 162.1 **HEAT PIPES** 36.5 CONTROLS 33.0 SUPPORT STRUCTURE 22.7 TOTAL MASS 346.3 REACTOR SPECIFIC MASS 0.66£ kg/kW,

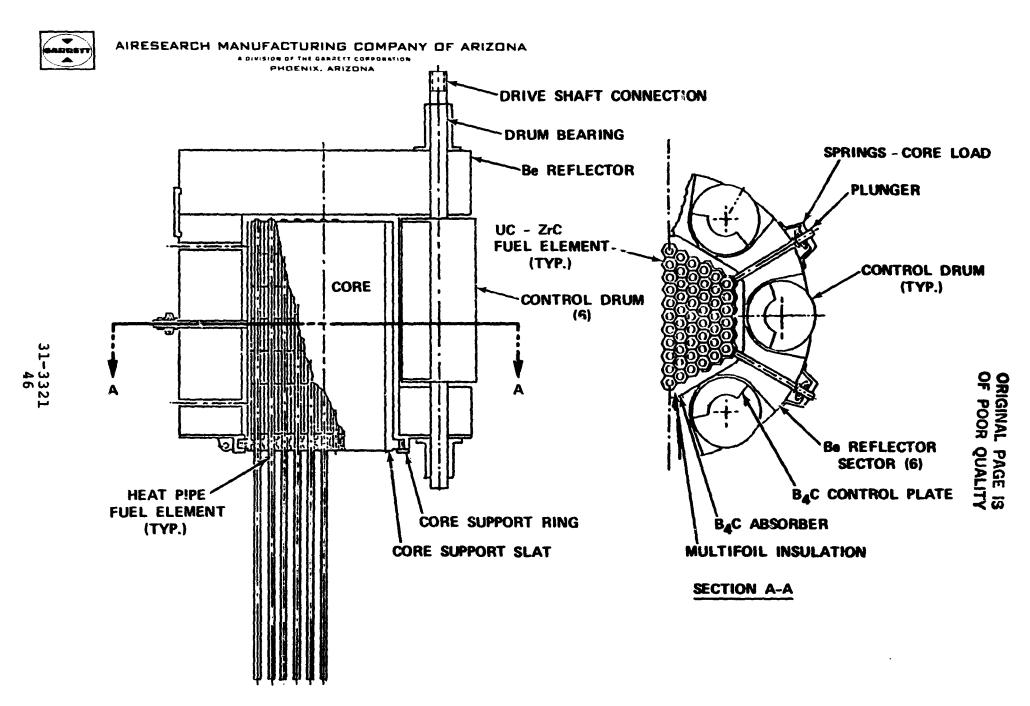


Figure 22. LASL Reference Reactor Design Concept - 400 kWt (nom.)



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CO. PORATION PHOENIX, ARIZONA

ORIGINAL PAGE IS OF POOR QUALITY

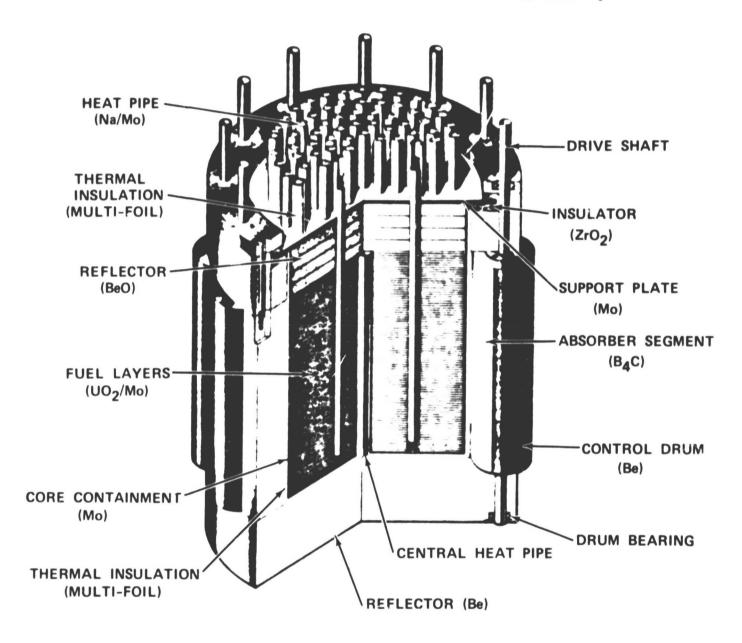


Figure 23. LASL Layered Core Heat Pipe Cooled Space Power Reactor Design Concept - 1200 kWt

# AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT CORPORATION PHODENIX, ARIZONA

#### Radiation Shields

The nuclear radiation shielding has not been given detailed attention since the requirement is similar to the design used for the thermionic systems. Tailoring of the lithium hydride neutron shield to reduce its mass is shown in Figure 19. The propellant tank is located so that it can be used as a gamma radiation shield and is sized to hold an additional quantity of mercury for this purpose.

#### 2.3.3 Heat Source Heat Exchanger

The heat source heat exchanger (HSHX) is the highest temperature component of the closed cycle system(s). This component looks like a typical tube fin heat exchanger and is illustrated in Figure 24. The geometry and performance are also summarized on this chart. The operation differs from a normal heat exchange because this design has equal heat flux from each tube. This occurs because each tube is actually the condensing end of a heat pipe. The heat pipe receives its heat in the nuclear reactor and gives it up in the heat exchanger. The heat is transferred to the working fluid by convection from the heat pipes and fins. In the reference system, the HSHX receives working fluid from the recuperator at 1114°K and provides it to the turbine at 1500°K.

There is a heat source heat exchanger for each power system. Because of the nature of heat pipes, when each evaporator section is operated at half power (the nominal operation), the maximum metal temperature is reduced from the 1583°K (the value when only one section is in use). This heat exchanger is all-molybdenum construction. This material is also used in the heat pipes.

### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA PHDENIX, ARIZONA

**CHARACTERISTICS** GEOMETRY: **FINNED TUBE** TUBE OD = 2.5 cm (1 in.) NO. FIN/cm = 10 (25 fins/inch) FIN LENGTH = 0.5 cm (0.2 in.) FIN THICKNESS = 0.25 mm (0.010 in.) NO. FINNED TUBES = 162 CONDENSING LENGTH = 41.2 cm (16.2 in.) GAS FLOW LENGTH = 67.8 cm (26.7 in.) HEAT EXCHANGER WIDTH = 33.0 cm (13 in.) **PERFORMANCE** MAX WALL TEMPERATURE = 1583°K (2390°F) CONDUCTANCE = 21 kW,/°K (11Btu/sec-°F) FIN EFFECTIVENESS = 67 PERCENT EQUAL HEAT FLUX PER TUBE ALL MOLYBDENUM CONSTRUCTION

Figure 24. Heat Source Heat Exchanger Concept and Characteristics

ORICINAL PAGE IS OF POOR QUALITY



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA

#### 2.3.4 Combined Rotating Unit

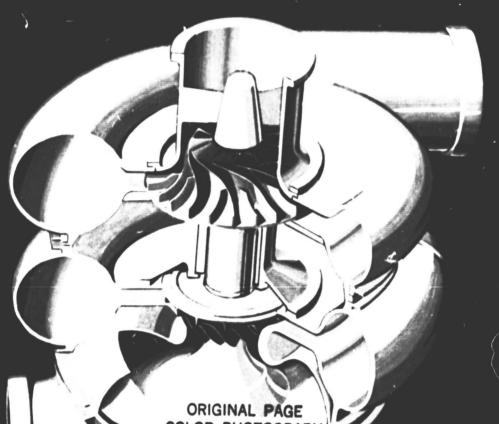
The combined rotating unit (CRU) is a highly efficient, single shaft, closed Brayton cycle design that has resulted from many years of development and test in industry and government, especially under NASA sponsorship. Figure 25 is a rendering of the engine. The three primary components are the compressor, turbine, and alternator.

The compressor is a state of the art design. It is radial outflow type with backward curved blades for maximum efficiency. The turbine is the radial inflow type with straight radial blades. It is also state of the art aerodynamic design.

Both the compressor and turbine are relatively small wheels. Moderate specific speed and relatively high Reynolds number result in high component efficiency. The actual design parameters are shown in Table 6.

Prior experience indicates that the CRU bearings are one of the most critical components for a long life space power system. The alternator is mounted on one pair of foil journal bearings. The compressor and turbine are mounted on a larger pair of similar bearings. Two sets of foil thrust bearings absorb the aerodynamic thrust of the compressor and turbine. Foil-type gas-lubricated bearings are designed such that all excursions are absorbed by a film of gas, which together with the foil, has a definable spring constant. With proper design, the rotor does not contact any bearing surface after it achieves a small fraction of the normal rotational speed during start. Because nothing rubs, there is no wear-out mode.

The alternator has a high performance samarium cobalt rotor. This rotor is smaller and lighter than a Rice alternator. Because it is smaller, the windage loss is much smaller. The alternator has the following performance:



**(1)** 

ORIGINAL PAGE COLOR PHOTOGRAPI

#### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GAP SETT CORPORATION PHDENIX, ARIZONA

### TABLE 6

### TURBINE AND COMPRESSOR WHEEL CHARACTERISTICS

	Turbine	Compressor	
Pressure Ratio	2.01	2.18	
Tip Speed	440 m/sec (1440 ft/sec)	400 m/sec (1300 ft/sec)	
Mean Specific Speed	62.0 rpm-ft $^{3/4}$ /sec $^{1/2}$	58.5 rpm-ft $^{3/4}$ /sec $^{1/2}$	
Tip Diameter	23.4 cm (9.2 in.)	21 cm (9.3 in.)	
Reynolds Number	380,000	$24 \times 10^6$	
Mass	11.4 kg (25 lb) Refractory or Advanced Superalloy	2.7 kg (6 lb) Titanium	
Efficiency	91 Percent	86 Percent	
Comments	o State of the art aero dynamic design	o High efficiency because cf low pressure ratio, moderate specific speed	
	o Relatively small wheel with low tip speed	and Reynolds number	
		o Low risk aerodynamic design	



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA PHOENIX, ARIZONA

Efficiency 96% without windage

Output 408 kW<sub>e</sub> Frequency 3000 Hz

Voltage 500 Line-to-Neutral

The alternator is mounted adjacent to the compressor rather than the turbine so that it has a lower temperature environment. The alternator is cooled by heat pipes. The heat is dumped by the alternator heat pipe radiator.

### 2.3.5 Recuperator

The recuperator is the component which enables the high efficiency of closed Brayton cycle engines. It exchanges the heat from the turbine discharge gas to the colder gas leaving the compressor. Extensive recuperation leads to relatively low-pressure ratios in the turbomachinery. Low-pressure ratio yields simple, highly efficient compressors and turbines. The mass of the turbomachinery is also reduced. All of these beneficial results require increased recuperator mass. Shotgun plots such as Figures 5 through 12 illustrate this effect, revealing the best combination of components to be selected for each application.

The recuperator is shown in Figure 26. It is a pure counter flow design to minimize mass. Each flow is split and moves through alternate finned passages. The heat from the turbine discharge gas is exchanged by convection to the fin and wall and thence to the other gas stream. Each stream is completely sealed from the other.

The selected recuperator uses a conventional fin design of 8 fins/cm (20 fins/in.). The heat transfer data were derived from AiResearch development testing. Similar finning is used in present production units. The computer code uses this data tog. ther with the



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA PHOENIX, ARIZONA

ORIGINAL PAGE IS OF POOR QUALITY

### **CHARACTERISTICS**

88% **EFFECTIVENESS** 

WELL WITHIN STATE-OF-THE-ART

1.6% TOTAL PRESSURE DROP  $(\Delta P/P)$  =

48 cm (19 INCHES) OVERALL LENGTH

79 cm (31 INCHES) HEIGHT

41 cm (16 INCHES) WIDTH 365 kg (805 lb<sub>m</sub>) **MASS** 

1552 kW, (1471"BTU/SEC) HEAT TRANSFER RATE

HOT END MUST BE REFRACTORY (Cb) **MATERIAL** 

COLD END COULD BE SUPERALLOY (HAST-X)

OTHER ASSEMBLY OPTIONS

REFRACTORY HEAT PIPE HOT END, HAST-X USED AT TEMPERATURES BELOW 1033°K (1400°F)

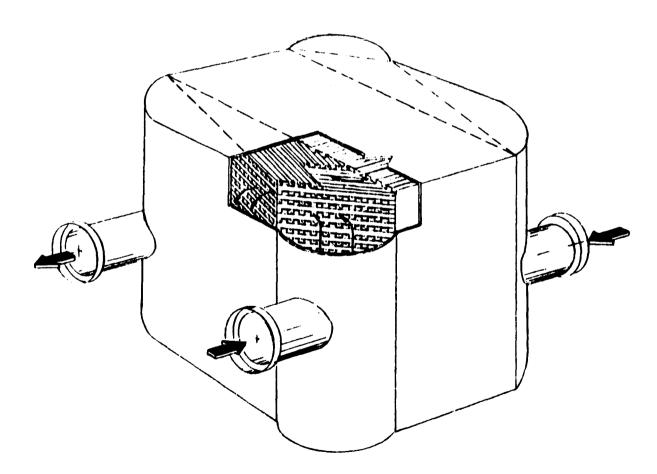


Figure 26. Recuperator Design Concept and Characteristics



### AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A BIVISION OF THE ABSOLUT SERVICION PHOENIX, ARIZONA

gas properties, state point, and desired effectiveness and pressure drop to calculate the geometry and mass of this heat exchanger.

Each recuperator has a mass of 365 kg (805 lb). The effectiveness of 88 percent is easily within the state of the art. (Effectiveness defines the percentage of heat available from the turbine exhaust gas which is transferred to the compressor discharge gas.) The design is compact, with dimensions shown on Figure 26. The only area needing development is manufacturing technology. Analytical study is needed to define the assembly method. The refractory materials are well-characterized, but some work is needed to demonstrate joining techniques. Other heat exchange/manufacturing options are available and should be explored.

### 2.3.6 Heat-Pipe Radiator Design

The heat-pipe radiator is the largest and most massive component in the power system. This radiator rejects the fraction of the input heat that is not converted to electricity to the sink of space. Figure 27 illustrates the heat balance for the entire system. The geometry of the radiator is defined by the closed cycle engine design program. This geometry is a function of heat rejection rate, compressor inlet temperature, pressure drop, and flow rate. This radiator was designed to fit into the Space Shuttle bay.

The cylindrical radiator is composed of eight identical panels. The amount of bending of the heat pipes required to yield the cylindrical geometry has no deleterious effect on the heat-pipe performance, according to Thermacore. The manner in which these panels overlap is shown in Figure 28. The gas heat exchanger of each radiator is protected from micrometeoroid penetration by the overlapping heat pipes from the adjacent panel. A multifoil insulation blanket is also sandwiched between the gas heat exchanger and heat rejection panel to provide thermal isolation and additional micrometeoroid protection.

### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARACTET COMPONATION PHODENIX, ARIZONA

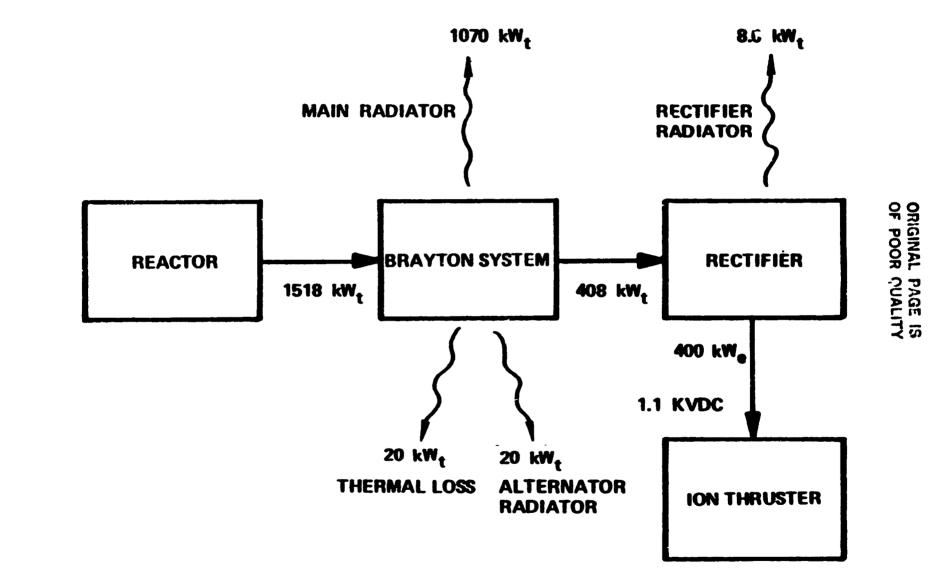


Figure 27. Heat Balance for 400-kWe Brayton Power System.



### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

A DIVISION OF THE GARRETT CORPORATION PROENIX, ARIZONA

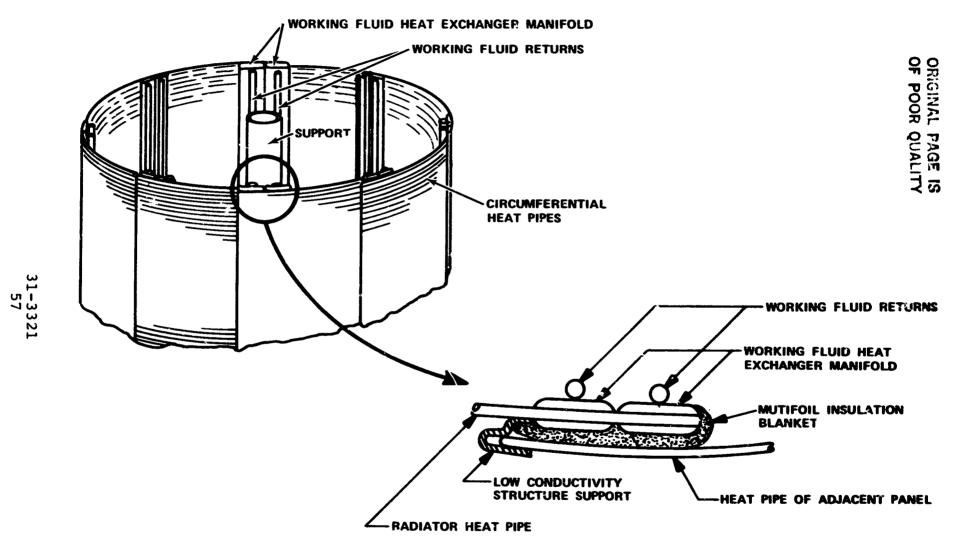


Figure 28. Cylindrical Heat Pipe Radiator Conceptual Design



# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARRETT CORPORATION PHODRIX, ARIZONA

Figure 29 is an illustration of the heat-pipe radiator that shows the gas heat exchanger, heat pipes, and fin. There are two gas heat exchangers, either of which can carry the entire thermal load to the heat pipes. When both redundant power systems are operated at half power, each heat exchanger carries half of the thermal rejection load. In any event, the radiator panel always carries the entire thermal load.

Figure 29 also lists the performance of the hot-end and cold-end heat pipes as well as the geometry of the gas heat exchanger. Diameter of the evaporator heat pipes is 2.5 cm (l in.) to achieve adequate gas-side heat transfer area. The diameter of condenser heat pipes varies from 0.6 to 1.3 cm. This use of dual diameters greatly reduces the mass of armor from that which otherwise would have been required. The mass of the heat sipes is also reduced.

As the data in Appendix A show, the smaller diameter heat pipes have adequate heat-transfer capacity with reasonable temperature drop down the pipe. Clearly, a larger diameter heat pipe would have a greater heat transfer capacity. While analytical methods have not been fully characterized for a tapered pipe (e.g., a large diameter evaporator coupled to a smaller diameter condenser with a short tapered transition), such pipes have been fabricated and tested. Thermacore has concurred that this approach is basically sound and that there should be very little uncertainty of the feasibility of such a pipe.

A mass summary for the radiator is given in Table 7. The two largest contributors are the gas heat exchanger and heat pipes. Some mass reduction in the heat pipes is possible if thinner walls are used (the present design has a wall thickness of 3 to 6 percent of diameter). Mass reduction is also possible with the new armor design being investigated by Thermacore. Furthermore, the mass of the gas heat exchanger could be reduced by use of composite materials. Some



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT COMPONATION PHOENIX, ARIZONA

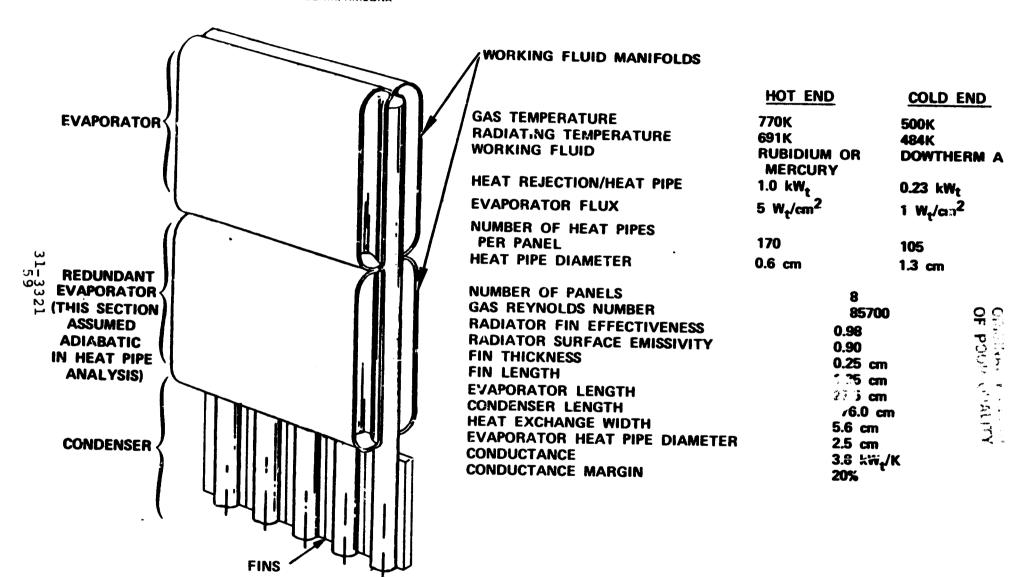


Figure 29. Heat Pipe Radiator Heat Exchanger Design Concept and Characteristics.

## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SAMELY COMPONATION PHODENIX, ARIZONA

#### TABLE 7

#### MASS SUMMARY FOR RADIATOR WITH DUAL-DIAMETER HEAT PIPES

Component		Mass, kg
Evaporator Heat Pipes		766
Heat Exchanger Wrap Up		1433
Condenser Heat Pipes		650
Armor		439
Fins		752
	Total	4040



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT COMPANIEN PHODENIX, ARIZONA

slight reduction in fin mass is also possible. Summing these contributions would result in a total radiator mass of less than 3800 kg. This would reduce the system specific mass (Jovian environment) to  $20~\rm kg/kW_{\odot}$ .

Stainless steel was selected for the heat pipes because of its compatibility with the heat pipe working fluids. Steel was also selected for the gas heat exchanger because of its strength to weight ratio. Beryllium or Lockalloy (Be38Al) was selected for the armor because of its low density, high modulus of elasticity and high thermal conductivity. Either of these materials could also be used for the fin because of low density and high conductivity.

#### 2.3.7 Power Conditioning and Associated Heat Rejection

The power conditioning is accomplished by a solid state device which converts 500 VAC line to neutral to 1100 VDC. This device is basically a bridge rectifier. Efficiency is 98 percent.

The waste heat from this device must be rejected to space. A separate heat-pipe radiator is used. The evaporator is thermally attached to the appropriate electronics. The condenser is attached to a fin and radiates the waste heat to space. For the 400-kW<sub>e</sub> NEP, this radiator is a right circular cylinder 0.6 m high and 4 m in diameter. During launch, this radiator is stored inside main radiator with the payload. After launch, the radiator and p. oad are deployed, allowing the closed cycle engines and thrusters to be activated.

#### 2.3.8 Alternator Radiator

As shown in Figure 27, the alternator radiator must remove  $20~\mathrm{kW_t}$ . This radiator comprises the aft 2 m of the 3.2 m diameter cylindrical enclosure of the power system which is sufficient to maintain the alternator temperature at  $390^\circ\mathrm{K}$  (240°F). Contact with ion engine designers indicates that there will be minimal interaction with ion beam and that thin graphite coatings ( $\epsilon \approx 0.85$ ) will provide satisfactory erosion resistance.



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOSENIX, ARIZONA

#### 3.0 CONCLUSIONS

Current results clearly show that a nuclear electric spacecraft with a 400-kW reactor Brayton power system can be placed in orbit by a The 400-kW<sub>e</sub> reference system identified by single Shuttle launch. this study employs a 1990 technology turbine inlet temperature of 1500°K (2240°F) using available refractory alloys and other conservative design parameters. Practical systems over the power range from 100 to 1000 kW, have been identified with TITs from 1325 to 1650  $^{\circ}$ K, and possibly 1800°K. Essentially current (1985) to projected (1995) technologies are represented, utilizing materials from superalloys to high-temperature refractory alloys and, ultimately, to ceramics. Use of a head-pipe-cooled reactor, independent redundent power conversion loops, and heat-pipe radiators eliminates the single-point failure modes The specific mass performance parameter for the 400-kW power level is within 5 percent of the goal of 20  $kg/kW_{\mbox{\scriptsize e}}$  which compares favorably with power systems based on other conversion means. Further refinement of the 400-kW system design with the new LASL layered core reactor, specifically tailored Brayton components, and more detailed design of the primary radiator based on new heat-pipe concepts will provide specific system masses below 20 kg/kWa.

The heat-pipe cooled reactors now being defined by LASL utilize a relatively new concept that employs advanced technology. These reactors have great promise for broad applicability. Substantial research and technology work as well as subsequent development and testing are needed and should be strongly supported.

While closed Brayton cycle technology is receiving support because of its breadth of recognized applications, the special requirements for space service (e.g., performance parameters such as low specific mass, high efficiency, and reasonable specific radiator area; very high reliability with long life; and low comparative costs) need to be evaluated by parametric systems analysis and subsequent



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARRETT COMPANY OF ARIZONA PHOENIX, ARIZONA

research and technology work. Typical topics that need to be addressed include high-temperature materials, advanced heat exchangers, rotating machine elements including bearings, heat-pipe space radiator concepts, power processing elements, etc. Broad research and technology efforts in applicable types of advanced heat pipes are especially needed.

Future space missions are currently not well enough defined to permit proper focusing of technology and development efforts. More detailed optimizations of various classes of advanced missions are needed combining spaceflight trajectory analysis and parametric systems analysis with programmatic factors in the 1990 to 2010 time frame and beyond. This work is needed to help identify the kinds of technology that will be most useful and its timing.

Based on the study results, space power systems that use closed Brayton cycles may well find application in future nuclear electric spacecraft when definitive comparisons with other systems that include all pertinent factors are completed. Clearly, further work is needed to ascertain the degree and extent of the promise of CBC system vis-avis the competing power conversion systems.



## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA

#### 4.0 RECOMMENDED FURTHER STUDIES AND ANALYSES

Based on results of the work accomplished in this study as well as previous efforts over many years on space power system development, the following recommendations are made for further studies and analyses of reactor Brayton power systems for nuclear electric spacecraft. In order to keep a technology viable, some continuity of effort is needed that keeps a minimum level of effort active. This is especially true at present when the new capabilities of the Space Shuttle transportation system are beginning to be understood and exploited. The Shuttle will have an increasing influence on the course of solar system exploration in the late 1980s, 1990s, and beyond, especially as the contribution of nuclear electric rocket propulsion is realized. Closed Brayton cycle power conversion, in toth its established and advanced forms, has a role to play in the space power systems that are needed for solar system exploration, as well as a wide variety of other missions.

#### 4.1 Refined System Designs, Including Reliability-Life Characteristics

The conceptual design of the 400-kW<sub>e</sub> reference system should be refined to include LASL's new layered core reactors, specifically designed Brayton components, and detailed design of space radiators based on well-developed heat-pipe data. It may be desirable to investigate other specific power levels; for example, the currently identified 1200-kW<sub>t</sub> LASL layered core reactor would provide between 250 and 350 kW<sub>e</sub> using a Brayton power conversion system. In addition to determination of performance parameters in greater detail, it is timely to undertake the introduction of reliability and life factors in the analysis. The conversion of the present system design code into a parametric systems analysis code with modular elements should also be investigated.



## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT CORPORATION PHOENIX, ARIZONA

#### 4.2 Advanced Component Design

Current analytical techniques do not allow tailoring each Brayton component in detail for specific mission as well as system requirements. AiResearch recommends that the effect of novel heat transfer concepts, materials, configurations, and other requirements be investigated for the major Brayton components. A typical system design, such as the current 400-kW<sub>e</sub> approach, would form the basis for this effort. Such important considerations as reliability, life, and cost need to be included as well as performance tradeoffs.

#### 4.3 Space Radiator Designs with Advanced Heat Pipes

The primary heat rejection radiator is the dominant element in Brayton power systems for space applications. Special attention should be given to further conceptual design and analysis of space radiators with advanced heat pipes configured especially for this use. Many neoteric heat pipe designs, with wall materials and working fluids matched to the specific requirements of temperature, shape, meteoroid protection, and other pertinent requirements, should be evaluated.

#### 4.4 System Operations and Safety

A study is recommended of the operational requirements of Brayton systems in space power service. The various operational phases such as system assembly, ground checkout, launch operations, orbital transfer, automated start-up, and power system regulation in space need to be studied and analyzed, especially with respect to their effect on overall system safety. Interactions of the Brayton components with the nuclear subsystem, spacecraft, and space transportation systems should be evaluated in, at least, an introductory manner. Preliminary outlines of the required system safety documents should be generated for interactive discussions with cognizant agencies.



## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A BIVISION OF THE SAMELY COMPONATION PHODENIX, ARIZONA

#### 4.5 Probability of Mission Success

The influence of the power system on the probability of mission success and the design and operational characteristics of the Brayton components are recommended for study in detail. This will require definition of typical missions in terms of mission goals and operational sequences. Since nuclear electric spacecraft will be used for complex missions throughout the solar system for durations of ten or more years, these reliability/availability studies are required to maximize the probability of performing a wide variety of missions successfully.

#### 4.6 Economic Analyses Including Risks

Although non-recurring and recurring costs of Brayton power systems for space cannot be determined now with satisfactory accuracy (since only conceptual system designs and sketchy mission application information are available), it is not too soon to begin to develop the methodology for economic analysis. At the least, this will result in the necessary data being identified. Economic analyses of advanced systems, especially if they are to deal with risk, must be conducted on a probabilistic basis. Since it is necessary to keep such analyses as simple and clearly defined as possible, as appropriate to the available data and sophistication of the results, it is strongly recommended that the methodology for such analyses be formulated relatively early in the development program.

#### 4.7 Space Shuttle Compatibility

An understanding of the Space Shuttle transportation system in some detail is necessary to be sure the Brayton-powered, nuclear electric spacecraft will be compatible with ground, launch, and space operations. Early attention to the detailed interfacing of the Brayton power system with the nuclear electric spacecraft and the Space Shuttle orbiter in all regimes is recommended.

## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA

#### 5.0 RECOMMENDED TECHNOLOGY EFFORTS

In general, the closed Brayton power conversion system can be characterized as a mature technology ready for application (e.g., flight system development). The rather unusual operating conditions\* required for the optimal systems defined in this study engenders a requirement for technology development in certain areas. Also, it must be recognized that there is currently very little supporting research or advanced technology either underway or being proposed which is aimed specifically at the requirements of space Brayton systems. Therefore, this section addresses these supporting technology needs and defines a preliminary schedule. This program would result in the required technology being demonstrated by target dates that are commensurate with current projections of flight system applications.

As summarized in Figure 30, a scenario of projected technology utilization for prospective flight applications has essentially been developed in Section 2.0 of this report. This figure indicates that the power requirements will increase exponentially with time. As described previously, a five-year flight system development and qualification program is assumed; therefore, technology readiness\*\* needs to have been demonstrated five years before the proposed launch date.

<sup>\*</sup>In terms of past space studies as well as more contemporary analyses of terrestrial power systems, the results of this study are characterized by lower efficiencies, higher ratios of CIT to TIT and lower recuperator effectivenesses to minimize the radiator mass and, thereby, the system mass.

<sup>\*\*</sup>Technology readiness is that stage of system, subsystem, or component development where all major problems associated with achieving the specified on performance goals have been solved and where the solutions to problems have been successfully demonstrated through actual hardware design, fabrication, and test programs. At this stage, there remain no major risks for an agency or contractor in scaling up the technology (if full-scale demonstration has not been performed) and in proceeding with mission/commercial development of the system, subsystem, or component.

#### 

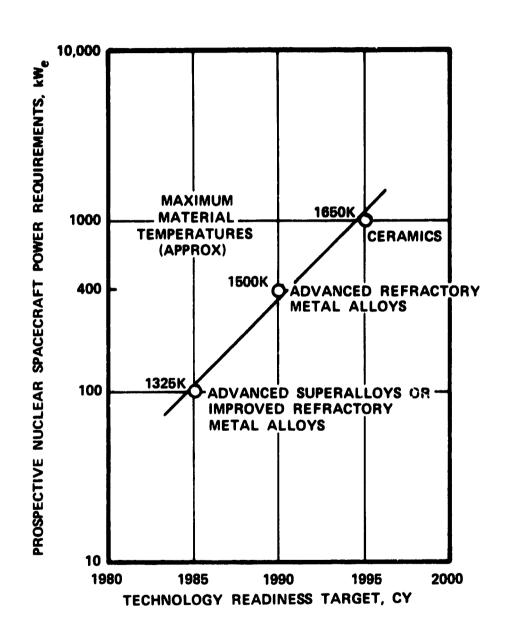


Figure 30. Prospective Nuclear Spacecraft Power Requirements Versus Technology Readiness.

## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

Figure 30 shows three increasingly stringent levels of nuclear reactor powered system applications:

- o 100-kW power systems in the early 1990s
- o 400-kW power systems in the mid 1990s
- o 1000-kW power systems at the turn of the century

A schedule which lists the technology development areas required for increasingly sophisticated missions is shown in Figure 31, and discussed in some detail subsequently. It is important to note that approaches to the required technology can be defined at this time, e.g., no fundamentally new technology or "technical breakthrough" is required.

In projecting the technology requirements, the reactor heat source is not included. It was assumed that the current LASL development program will continue under independent sponsorship and that this program will yield the reactor technology as it becomes required.

#### 5.1 100 kW System Technology

The current application forecast for this system is geocentric orbital power. Because of the large Shuttle lift capability for this class of missions, it is not necessary to achieve minimum system mass or volume to have a viable approach. This resulted in the choice of the 1325°K TIT, as noted previously.

The most necessary technology for this class of missions is in the area of materials. Current superalloys are limited to 1144 to 1172°K (1600 to 1650°F). Late developments in alloy modification using rapid solidification with powder metallurgy have currently resulted in allowable TIT increases of 56 to 83°K (100 to 150°F) with further improvement possible.



#### AIRESEARCH MANUFACTURING COMPANY OF ARIZONA

PHUENIX, ARIZONA

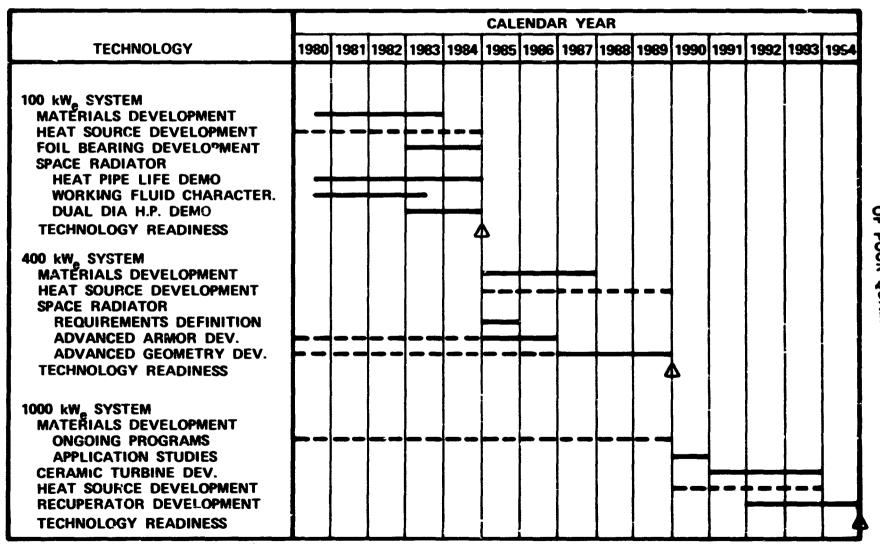


Figure 31. Schedule of Key Power Conversion Technology Elements Required for Reactor/Brayton Space Power Systems.

## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHODENIX, ARIZONA

The relatively well characterized refractory metals such as niobium have adequate stress carrying capabilities but questions regarding potential degradation due to even the low oxygen partial pressure which exists in near-Earth space must be resolved. For example, the durability of existing anti-oxidation coatings in the hard vacuum of space must be established.

A substantiated bank of standardized design data needs to be assembled, including definition of design nominals and minimums as well as an accepted methodo ogy for life projection. Thus, a fairly comprehensive materials characterization effort will be required.

The reactor heat pipes are exposed to the highest temperatures in the closed loop and, as previously noted, will be made from refractory metals such as molybdenum or niobium. Methods of efficiently integrating these heat pipes into the heat source heat exchanger need to be studied, analytically and empirically. Potential approaches include an all-refractory metal design as well as one in which the heat exchanger wall could be made from metal, using internal insulation to limit hot spot exposure. In the latter case, either a thermally resilient seal between the refractory and superalloy or a weldment/brazement into a diaphragm-type thermal stress relief might be used.

In recent years, foil type gas bearings have come into increasingly wide-spread use in various commercial turbomachinery. For example, the boarings on the DC-10 air-conditioning air cycle units have accumulated over 53 X 10<sup>6</sup> bearing operating hours of operation and currently exhibit a mean time between bearing failure of 249,000 hours. Concurrently with these applications, dramatic strides advanced this technology from an empirical base to a discipline solidly supported by analysis and field operation. However, this analytical characterization effort has recently stagnated. To provide a proper technology base, this effort needs to be re-instituted to



## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT COMPONATION PHOENIX, ARIZONA

establish a uniform methodology (including analytical, fabrication, inspection, and performance verification) for a variety of applications including space power systems. An important element is the development of a hydrodynamic/elastic computer model. The derivation and empirical verification of the predictions of such a model will be extremely significant in the avoidance and/or timely correction of problems during future applications.

The heat-pipe radiator for the 100-kWe system (Figure 4) requires very little extension to existing technology. A ground-based, horizontal, extended life test of heat pipes using Dowtherm A and either mercury or rubidium working fluids should be instituted as early practical to demonstrate that no unanticipated life-limiting mechanisms will be encountered. The data base for rubidium, especially, and mercury, to a certain extent, is insufficient for the heat-pipe designer's needs and should be expanded. The thermal decomposition or other life-limiting behavior of Dowtherm A should be investigated thoroughly as a function of temperature. To cut down the radiator mass, a statistically significant number of dual diameter (large evaporator, small condenser) heat pipes should be fabricated and subjected to thermal performance limit testing. Space testing of representative heat pipe designs should be undertaken at the earliest practical opportunity.

#### 5.2 400-kW System Technology

Since the interplanetary spacecraft propulsion system uses the full Shuttle launch capability both in terms of injected mass and payload bay volume, power system performance is critical. Therefore, a higher TIT was selected for this system. In discussing the technology development implications for support of this system, it has been assumed that the items described in the preceding paragraph will have been completed, either in support of the 100-kW<sub>e</sub> system development or under other program sponsorship in the intervening period.



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE GARRETT CORPORATION PHOENIX, ARIZONA

The biggest payoff for the 400-kW<sub>e</sub> system is in the area of heat-pipe space radiator technology development. A comprehensive effort should be completed to evolve the most realistic set of environmental design requirements, particularly in the definition of micrometeoroid flux levels. The variations in such exposure over the candidate missions should be defined so that the armor is designed realistically.

Armor geometries, materials, and manufacturing and application techniques should be investigated to minimize the penalty due this factor. The results of the current Thermacore study suggest that this topic has only recently begun to be pursued in the required depth. However, it may well have been completed prior to 1985, as the dashed line in Figure 31 indicates.

A concomitant effort on the investigation of the performance improvements possible by using advanced geometry heat pipes should also be completed, if not accomplished in the intervening years. Configuration-pumped and mechanically-pumped heat pipes are examples of the advanced types that need to be considered.

Additional materials development will be required to enable the 1500°K TIT (Figure 18) to be attained. Molybdenum and tantalum alloys are the leading candidates. The data base on these materials is sketchy and quite dated; thus, a significant effort in this area is indicated. Machinability, manufacturability, joining, and space environment tolerance under operating conditions are additional topics that will need to be addressed.

It will also be necessary to integrate the more advanced refractory materials into the heat source heat exchanger. It is believed that techniques which will have been developed for the  $100-kW_e$  heat source will be applicable, but this needs to be confirmed.

## ----

## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE SARREST COMPONATION PHOENIX, ARIZONA

#### 5.3 1000-kW System Technology

The projected missions and launch vehicles for this class of power systems are in the very early definition phase. Thus, it cannot be stated unequivocally that the higher performance selected for this system will absolutely be required. In the eventuality that lower performance is acceptable, the 1000-kW<sub>e</sub> missions could be accomplished by ganging three of the 400-kW<sub>e</sub> systems with a fourth as the redundant spare to yield an overall system with fairly respectable performance specifics.

However, it must be recognized that the historical trend in aerospace is to use the available technological capability to the fullest. Few rocket-powered vehicles have been launched that used only a fraction of their lifting capability, and there is little reason to suspect that this trend will change in the future (early projections regarding the usage of the space transportation system not withstanding). Therefore, this section will address technology development required to support the CBC systems operating at a TIT of 1650°K (2510°F) as listed in Figure 30.

In common with the systems described previously, the largest implication is on the materials needed for the high temperature components. As noted in Section 2.1.4 and indicated by the dashed line in Figure 31, the ceramic technology needed for this system is currently under active development for a number of programs. The differing requirements of the space power system will necessitate that a thorough analytical study, with possibly some supporting empirical effort, be undertaken to define how this technology may best be applied.

Following this effort, three fabrication/demonstration efforts associated with materials integration into critical components should be pursued. The ceramic turbine and associated static components



## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DISSELLE OF THE GARRETT CORPORATION PROCESSIX, ARIZONA

should be fabricated and assembled unless prior efforts have shown that components of the appropriate scale and materials have already been achieved. Most probably, ceramics will have to be used extensively in the reactor and ceramic heat pipes will be used between the reactor and heat source heat exchanger. The approach for providing extended surface on the condenser end in the heat source heat exchanger and the methods for sealing and integrating the heat pipes through the wall (ceramic or metallic) of the heat exchanger must be developed and demonstrated. Higher temperature capability materials are also needed for the recuperator. However, this should be within the range of the advanced refractories that will have been demonstrated at that point. Therefore, a fabrication/assembly technology demonstration program with these materials should be accomplished.

## AIREBEARCH MANUFACTURING COMPANY OF ARIZONA A DIVISION OF THE BARRETT CORPORATION PHOENIX, ARIZONA

#### 6.0 REFERENCES

- 1. JPL Interoffice Memo-D.F. Bender to M.J. Cork, Nuclear Electric Performance Data for Outer Planet Orbiters and a Solar Escape Mission and a Comparison will SEP Performance, dated 15 December 1977.
- 2. Phillips, W.M. and Pawlik, E.V., Nuclear Electric Power and Propulsion System for Earth Orbital and Solar System Exploration Applications, AIAA/SAE/ASME 15th Joint Propulsion Conference Paper No. 79-1337, June 1979.
- 3. JPL Cost-Plus-a-Fixed Fee Research and Development Contract No. 955008.
- 4. Phase I of Ceramic Technology Readiness Program, DOE Contract Numbers EF-77-C-01-2664 with Garrett/AiResearch and EF-77-C-01-2786 with Westinghouse Combustion Turbine Systems Division.
- 5. Ceramic Gas Turbine Engine Demonstration Program, Navy Contract N00024-76-C-5352 with Garrett/AiResearch, sponsored by Advanced Research Projects Agency.
- 6. Conceptual Design Study of Improved Gas Turbine Powertrain, NASA Contracts DEN 3-37 with the Ford Motor Company and DEN 3-38 with Detroit Diesel Allison Division of General Motors, sponsored by DOE.
- 7. Thermacore, Inc., Preliminary Letter Report No. 1-Meteoroid Protection Methods for Spacecraft Radiators Using Heat Pipes, April 1979.
- 8. LASL Letter, D. Buden to A. Harper, Q-DO/SEPS, June 15, 1978.



## AIRESEARCH MANUFACTURING COMPANY OF ARIZONA A SINISION OF THE SAMELY ESSENTIAL OF THE SAMELY ESSENTIA

- 9. LASL Letter, D. Buden to A. Harper, Q-DO/ET, 4 August 1978.
- 10. LASL Letter, D. Buden to A. Harper, Q-DO/SEPS, 14 August 1978.
- 11. LASL Progress Report No. LA-7878-PR, Reactor Technology, January-March 1979, June 1979.

## AIRESEARCH MANUFACTURING COMPANY OF ARIZONÁ A DIVISION OF THE GARRETT SORPERATION PHOENIX, ARIZONA

#### APPENDIX A

PRELIMINARY LETTER REPORT #1
FROM
THERMACORE, INC.

(56 Pages)

# THERMACORE, INC.

April 1979

PRELIMINARY LETTER
REPORT

CONTRACT 955437

METEOROID PROTECTION METHODS
FOR SPACECRAFT RADIATORS
USING HEAT PIPES

PREPARED FOR

CALIFORNIA INSTITUTE OF TECHNOLOGY

JET PROPULSION ABORATORY

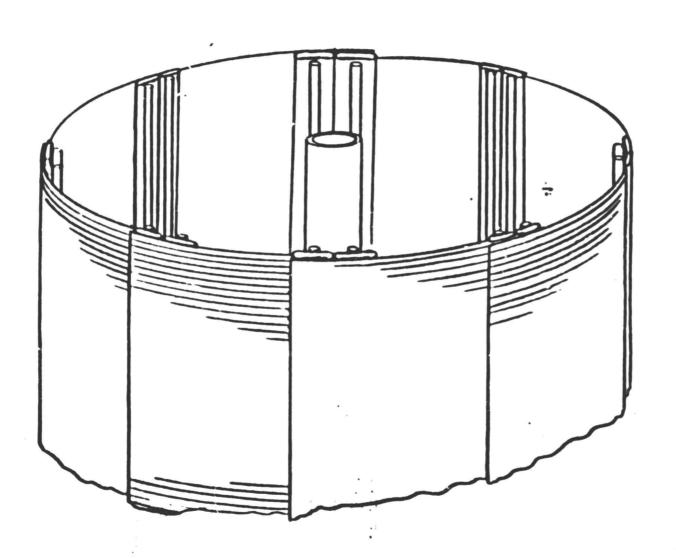
PASADENA, CALIFORNIA

#### HEAT PIPE DESIGN FOR CBC RADIATOR

The 400 kW Closed Brayton Cycl wower system for the Nuclear Electric Propulsion Spacecraft has been designed by Garrett AiResearch to use heat pipes to achieve a thermally effective radiator which has a high survival probability. It is also anticipated that the heat pipe design will lead to a low specific mass. The heat pipe design evaluated in this work is for use in a cylindrical array as seen in Figure 3.1. This design has eight dual gas-to-radiator heat pipe heat exchangers fed from a dual central duct. The heat pipes are attached to both gas ducts over a length of 43 cm on each duct. Thus, the heat pipes provide armor protection for the gas ducts.

In normal operation, the total 86 cm length attachment over the heat pipes to the gas ducts will be used as heat pipe evaporators. The condenser is 176 cm long. If either gas duct or engine fail, then the whole power load will be transferred to the heat pipes through only one of the 43 cm attachments. Accordingly, for design consideratin, the heat pipe must be sized as though it had a 43 cm evaporator, 43 cm adiabatic and 176 cm condenser.

Four different sets of heat pipe designs were analyzed with respect to mass and performance. However, no consideration was given to the required heat pipe armor and tradeoffs in the heat pipe diameter versus T-bar fins for total mass. The overall heat pipe cell dimension as designed by GAR is 3.175 cm (1.25") and includes heat pipe and fins. All heat pipes discussed in the Sections 3.1 and 3.2 have computer printouts of their performance tabulated in Appendix 1.



CBC RADIATOR CONFIGURATION

#### 3.1 Baseline Design

The total power to be dissipated is 1.1 x 10 watts. From the gas side of the radiator heat exchanger, heat pipe temperatures were calculated by Garrett AiResearch to range from 707°K down to 492°K. The power levels are 720 watts per heat pipe at 707°K and 169 watts per heat pipe at 492°K. Thus,  $\sigma A \varepsilon$  can be computed to be 2882 x  $10^{-12}$  watts/ $^{\circ} K^{4}$  from:

$$P = \sigma A \epsilon r^4$$

Equation 3.1

where

P = power radiated - watts

 $\sigma = \text{Stefan Boltzman Constant} = 5.67 \times 10^{-12} \frac{\text{watts}}{\text{cm}^2 - \text{o}^4}$ 

 $T = heat pipe temperature - {}^{O}K$ 

 $A = \hat{n}$  dividual heat pipe radiating area - cm<sup>2</sup>

 $\epsilon = e$  fective thermal emissivity

Table 3.1 shows the required heat pipe power for each of the end temperatures and each temperature divisible by 25°K.

Garrett AiResearch's baseline design is a 2.54 cm (1") 0.D. heat pipe with a 0.0762 cm (.03") wall. The optimum heat pipe designs under these conditions are seen in Table 3.2. Rubidium is the preferred heat pipe fluid from 707°K down to 650°K. Below 650°K Dowtherm A (DTA) is the preferred fluid. In both cases, a screen covered groove design is found to be the lowest mass system. The rubidium heat pipes have a 1.75 Kg mass. The DTA heat pipes have a 1.74 Kg mass.

Table 3.3 shows the same heat pipes, which have been, for the most part, optimized with respect to the number of grooves and their aspect ratio. The rubidium heat pipes have a 1.48 Kg mass. The DTA heat pipes have a 1.55 Kg mass.

### ORIGINAL PAGE IS OF POOR QUALITY

TABLE 3.1

Temper	rature	Req. Power
νκ	°c	Watts
707	434	720
700	427	6 92
675	402	598
650	377	514
625	352	440
600	327	373
575	302	315
530	277	264
525	252	219
500	227	180
492	219	169

## REQUIRED POWER PER HEAT PIPE AT ELEVEN DIFFERENT TEMFERATURES

TABLE 3.2

HEAT PIPE MASS & PERFORMANCE FOR BASELINE DESIGNS

Adiaba Conder S = Se	rator - atic - nser - 1 onic Lim apillary	43 cm .76 cm	Fluid: Rb Vessel: 304 SS   0.D.: 2.54 cm   Wall: 0.0762 cm   # Grooves: 25   Groove Width: 0.2 cm				Wall: 0.0762 cm 0.D.: 2.54 cm Wall:				2 cm 0.D.: 2.54 cm Wall: 0.0762 cm		
Tempe	rature	Req. Power	ΔT @ Req.	Power Limit	Nass	Groove Depth	∆T € Req. Power	Power Limit	Mass	Groo' e Depth			
o <sub>K</sub>	°c	Watts	°c	Watts	Kz	Cm	°c	Watts	Kg	Cm			
707	434	720	2.56	1750-S	1.75	0.05							
700	427	6 92											
675	402	598											
650	377	514	6.44	608-S	1.75	0.05							
625	352	440					3.89	545-C	₹.74	0.065			
600	327	373											
575	302	315		1									
550	277	264											
525	252	219											
500	227	180											
492	219	169					1.73	710-C	1.74	0.065			

TABLE 3.3

OPTIMIZED HEAT PIPE MASS & PERFORMANCE - BASELINE DESIGN

Evaporator - 43 cm  Adiabatic - 43 cm  Condenser - 176 cm  S = Sonic Limit  C = Capillary Limit		Fluid: 0.D.: 2.54 # Grooves:	em Wa	essel: all: coove Wid	Fluid: DTA Vessel: 304 0.D.: 2.54 cm Wall: 0.0762 # Groove: 25 Groove Width: 0.2					
Tempe	rature	Req. Power	ΔT € Req.	Power Limit	Mass	Groove Depth	ΔT € Req. Power	Power Limit	Mass	Groov Depti
ок	°c	Watts	°c	Watts	Кд	Cm	°c	Watts	Kg	Cm
707	434	720	2.43	815-C	1.48	0.02				
700	427	6 92								
675	402	598		!						
650	377	514	5.83	<b>640-</b> S	1.48	0.02				
625	352	440					9.32	<b>507–</b> C	1.55	.055
600	327	373								
575	302	315		;						
550	277	264		i						
525	252	219								
500	227	180								
492	219	169					3.55	555 <b>–</b> C	1.55	.055

#### ORIGINAL PAGE IS OF POOR QUALITY

The average mass reduction is 14%. Further optimization may result in ar additional 1 or 2% mass reduction. However, far greater mass reduction can be realized by 0.D. and/or wall thickness reduction.

Table 3.4 shows the 2.54 cm (1") heat pipe with a 0.025 cm (.01") wall. This wall thickness is 0.01 times the diameter and has been show. To be acceptable for use as a heat pipe containment vessel where external buckling is the ultimate constraint, i.e., the internal pressure of the heat pipe was less than 14.7 psi, thus long term creep due to hoop stress was low.

The use of a wall thickness 0.01 times the diameter was developed for Niobium, which has a modulus of elasticity of 15 x  $10^6$  psi. This includes a safety factor of 2. Stainless steels have moduli of about  $28 \times 10^6$  psi which reduces the thickness/diameter ratio to about 0.008 with a safety factor of 2. However, the use of 0.01 as a thickness to diameter ratio will be used to assure success.

Examination of DTA at 625°K shows a fluid pressure of 85 psi which develops a hoop stress of 4250 psi. This stress is acceptable, since 316 SS will only creep 0.1% in 10<sup>5</sup> hours at 1100°F under a stress of 6000 psi.

The rubidium heat pipes have a mass of 0.69 Kg and the DTA heat pipes have a mass of 0.78 Kg.

#### 3.2 Design Optimization

Examination of Tables 3.2, 3.3 and 3.4 reveals that a reduction in diameter of the rubidium heat pipes would soon result in the heat pipe going sonic. However, the DTA pipes are capillary limited, thus a reduction in 0.D. is possible. Accordingly, a higher pressure fluid, mercury,

TABLE J.4

OPTIMIZED HEAT PIPE MASS & PERFORMANCE FOR THIN WALLED BASELINE DESIGN

Adiaba Conder S = So	rator - atic - aser - 1 onic Lim apillary	43 cm 176 cm	Fluid: 0.D.: 2.54 # Grooves:	cm Wa	ssel: ll: oove Wid	304 SS 0.0254 cm th: 0.275 cm	Fluid: I 0.D.: 2.54 # Groove:	204 SS 0.0254 cm h: 0.275		
Tempe	rature	Req. Power	ΔT @ Req. Power	Power Limit	Mass	Groove Depth	∆T @ Req. Power	Power Limit	Mass	Groove Depth
ок	°C	Watts	°c	Watts	Kg	Cm	°c	Watts	Kg	Cm
707	434	720	1.55	820-C	0.69	0.02				
700	427	6 92		1						
<b>67</b> 5	402	598								
650	377	514	4.56	<b>70</b> 5-C	0.69	0.02				
625	352	440					5.72	555 <b>–</b> C	0.78	0.055
600	327	373								
575	302	315								
550	277	264								
525	252	219							ļ 	
500	227	180								
492	219	169					2.49	719-C	0.78	0.055

### OF POOR QUALITY

was used in small diameter pipes in place of rubidium. These results are seen in Table 3.5.

The mercury heat pipes are 0.635 cm (.250") in diameter with a wall to diameter ratio of 0.01. The mass of the mercury heat pipes are 0.45 Kg and have a hoop stress of 625 psi at 707°K.

The DTA heat pipes are 0.9525 cm (.37") in diameter with a wall to diameter ratio of 0.01. They have 12 grooves 0.275 cm wide by a depth that varies from 0.075 cm down to 0.05 cm. Accordingly, their mass varies from 0.31 Kg down to 0.27 Kg. The DTA heat pipes at 625°K will have a hoop stress of 1600 psi.

The mercury heat pipes of Table 3.5 have eight grooves 0.2 cm wide by 0.02 cm deep. Optimizing the number of 0.275 cm wide by .02 cm deep grooves for different power levels results in a reduction in mass. At 707°K, a five-groove heat pipe has a mass of 0.29 kg. At 675°K, four grooves have a mass of 0.28 kg and at 550°K, three grooves have a mass of 0.27 kg. These results are seen in Table 3.6. Also shown in Table 3.6 is the thermal performance of two of the mercury heat pipes with 86 cm evaporators, which shows an increase in maximum power capability and a reduction in total ΔT.

Both the DTA heat pipes of Table 3.5 and the mercury heat pipes of Table 3.6 have a performance  $\Delta T$ . Accordingly, one asks what does a  $\Delta T$  in the heat pipe mean in increased mass (length of condenser) to be able to radiate the required power? Appendix 2 develops Equation 3.2 which is the increase in mass of heat pipe due to its  $\Delta T$ .

$$dm = m \frac{1_c}{1_t} [(T_o/T)^4 - 1]$$
 Equation 3.2

TABLE 3.5

OPTIMIZED HEAT PIPE MASS & PERFORMANCE - ALTERNATE DESIGN

Adiab Conde S = S	rator - atic - nser - 1 onic Lim apillary	43 cm .76 cm	Fluid: 0.D.: 0.2952 # Grooves:	cm Wa	ssel: ll: oove Wid	304 SS .01 cm th: 0.200	Fluid: 0.D.: 1.27 # Groove:	7cm Wal	sel: l: 0. ove Widt	304 SS 0127 cm h:0.275
Tempe	rature	Req. Power	ΔT € Req. Power	Power Limit	Mass	Groove Depth	ΔT € Req. Power	Power Limit	Mass	Groov Depth
°K	°c	Watts	°c	Watts	Кд	Cm	°c	Watts	Kg	C∎
707	434	720	2.69	930-S	0.45	0.02				
700	427	692								
675	402	598					·			
650	377	514								
625	352	440	1.98	900-C	0.45	0.02	15.04	515-C	0.31	0.075
600	327	373					10.73	420–C	0.29	0.065
575	302	3 <b>1</b> 5					8.38	370-C	0.29	0.06
550	277	264	2.08	805-C	0.45	0.02	6.49	305-C	0.28	0.055
525	25 <b>2</b>	219					4.98	2 <b>40</b> -C	0.27	0.05
500	227	180								
<b>49</b> 2	219	169		<del></del>		<del> </del>	4.05	215-C	0.27	0.05

Adiab Conde S = S	nser - 176 cm  # Grooves: 3-5 Groove Width: 0.2 cm  # Groove: Groove onic Limit					11: 0.00	: 0.00635 cm ve Width: 0.2 cm			
Tempe	rature	Req. Power	△T @ Req. Power	Power Limit	Mass	Groove Depth	ΔT € Req. Power	Power Limit	Mass	Groove Depth
ок	°c	Watts	°c	Watts	Kg	Ст	°c	Watts	Kg	Cm
707	434	720	4.13	770-C	0.24	(5) .02	2.5	1625-C	0.29	(5) .02
700	427	692								
675	402	598	3.62	610 <b>–</b> C	0.28	(4) .02				
650	377	514								
625	352	440	3.30	445-C	0.27	(3) .02				
600	327	373								
575	302	315								
550	277	264	8.35	350-C	0.27	(3) .02	4.79	560-S	0.27	(3) .02
525	252	219								
500	227	180								
432	219	169								

ORIGINAL PAGE IS

#### ORIGINAL PAGE IS OF POOR QUALITY

where dm = increase in mass

m = initial mass of heat pipe

1 = length of heat pipe condenser

1, = total length of heat pipes

T = desired operating temperature

T = actual operating temperature

 $T_0-T = \Delta T$  down heat pipe

From Table 3.5 and 3.6, using the lowest mass reat pipes, the increase in mass was calculated using Equation 3.2 and is tabulated in Table 3.7. Therefore, to a first approximation, one can say that the heat pipes for the CBC radiator will have a mass of 0.3 Kg each.

The performance of the mercury heat pipes is based on perfect wetting, that is, the wetting angle is zero (0). For long term stability, this may not be the case. Wetting angles from 0-60 degrees have been observed, with 30-60 degree angles, the most common. Since the capillary force is a function of the cosine of the wetting angle, the mercury heat pipes may have a reduction of capillary force of up to 50% (cos 60 = .5). This reduction in performance will then require a reoptimization of the heat pipes with a small increase in mass.

TEMPERATURE	POWER	FLUID	MASS	<u>AT</u>	<u>du</u>	NEW MASS
(°K)	(W)		(Kg)	(°c)	(Kg)	(Kg)
707	720	Hg	0.291	4.13	4.6 x 10 <sup>-3</sup>	0.296
700 675	692 598	Нд	0.280	3.63	4.6 x 10 <sup>-3</sup>	0.284
650 625	514 440	Нд	0.273	3.30	3.9 x 10 <sup>-3</sup>	0.27/
600 5 <b>7</b> 5	373 315	Нд	0.273	5.81	7.5 x 10 <sup>-3</sup>	0,280
550 525	26 <b>4</b> 219	DTA DTA	0.280	6.49 4.98	1 x 10 <sup>-2</sup> 7.1 x 10 <sup>-3</sup>	0.290
500 <b>49</b> 2	180 159	DTA	0.273	4.05	6.2 x 10 <sup>-3</sup>	0.279

#### 3.3 Advanced Heat Pipe Concept

#### ORIGINAL PAGE IS OF POOR QUALITY

The groove heat pipe designs of Sections 3.1 and 3.2 optimized to an approximate mass of 0.3 Kg per heat pipe, exclusive of fins and armor.

This mass is quite low and may be acceptable in the overall system. However, there are several heat pipe design concepts which may offer further reduced mass with increased performance. These include but are not limited to arterial wick heat pipes and configuration pumped heat pipes.

#### 3.3.1. Arvery/Wick Hest Pipes

There is a natural division in heat pipe fluids which takes place at approximately 600°K. Above 600°K, the liquid metals are useful working fluids. Below 600°K, one generally deals with non-metallic fluids and devises structures which compensate for their inferior physical properties. The low temperature fluids, taken as a class, have relatively low latent heats of vaporization, low surface tension, and low thermal conductivity. The consequences are that for a given heat transfer rate, heat pipes using these fluids must move relatively large quantities of liquid with unusually low pressure losses, yet must maintain very thin liquid films in the heat flow path. The arterial wick structures of Figure 3.2 have been used to offset these property limitations. The artery provides the primary liquid return to the evaporator. This passage has a large hydraulic radius and provides a very low drag path. In the evaporator and condenser, a thin film of liquid is distributed circumferentially. The distribution wick is often a thin layer of screen or circumferential grooves.

The artery is removed from the evaporator and condenser heat flow paths. The thin films provided by the circumferential wick prevent the

### ORIGINAL PAGE IS OF POOR QUALITY

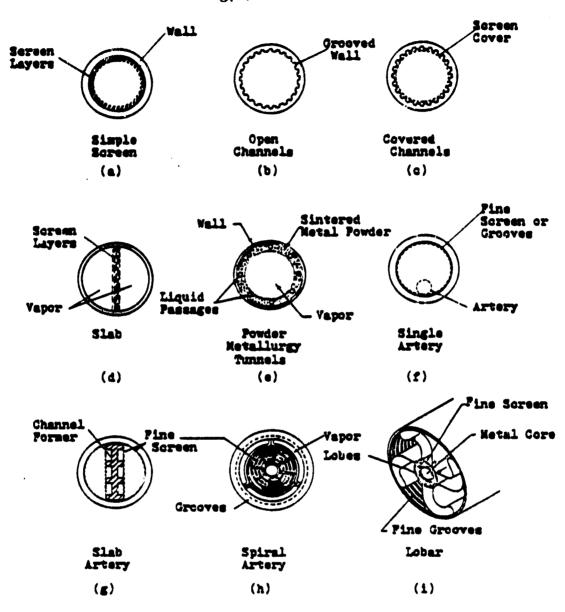


Figure 34.2 Representative Wick Geometries

development of excessive temperature gradients. Arterial wicks provide very high performance, sometimes even approaching that obtainable with liquid metals in more conventional wicks. Lengths in excess of ten meters have been reported. The primary limitations of arterial wicks lie in their difficulty of fabrication and their consequent lack of reproducible performance. The wick structures are quite difficult to form and to insert into the heat pipe vessel so as to maintain uniform close fit to the wall. There has been repeated difficulty with the priming of arteries, that is, the ability to fill an artery with fluid and keep it filled.

Two methods of priming are in use. Capillary priming, as the name implies, depends on capillary forces to maintain the fluid within the artery. The basic condition for capillary priming is that the largest single pore at the artery surface in the evaporator must provide sufficient capillary pressure to offset all counter forces including accelerations. Consequently, the evaporator ends of the arteries must be closed and there must be no single inadvertently large pore on the entire periphery of the enclosing surface. Due to the adverse effect of accelerations, capillary primed arteries can be more fractious during ground testing than in subsequent zero g operation. Yet ground testing is essential to establish the operability of the heat pipe.

If the artery is so located in the heat pipe temperature gradient that it always is the coldest spot, it will operate at a lower vapor pressure than the balance of the heat pipe. If the magnitude of the vapor pressure difference is sufficient, it will cause priming to take place. This is known as vapor pressure or Clapeyron priming. The process is highly temperature dependent. The pressure difference caused by a given temperature difference varies enormously with temperature. Thus, a heat pipe which primes reliably

and quickly at high temperature (i.e. high pressure) may fail to prime at all at low temperature. It has also been reported that vibration has caused arteries to lee their prime and that subsequent re-priming can be unreliable.

In spite of their apparent dramacks, the performance of arterial heat pipes is sufficiently high to justify further work to improve their reliability and reproducibility. In general, arterial wicks require less total mass of wicking material, and may also require less fluid inventory than conventional heat pipes. They are, therefore, serious candidates for use in space radiator.

# 3.3.2. Wickless (Configuration Pumped) Heat Pipes

A crevice has capillary properties. Therefore, if the wall of a non-round heat pipe is formed so as to produce longitudinal crevices, these may serve the purpose of wicks. That is, the configuration of the wall provides the capillary pumping force. Several potential configuration pumped heat pipe geometries are shown in Figure 3.3. Configuration pumped heat pipes have been tuilt (Figure 3.4) and have been shown to operate. However, there has been very little work in the field, and the mathematical prediction of performance is incomplete.

The driving pressure difference which causes liquid flow in a heat pipe is determined by the surface tension and the difference in the radius of the liquid meniscus in the condenser and evaporator. Evaporation in the heat input section tends to depress the liquid level while condensation at the heat output end tends to increase the level. Thus, during operation, the liquid level in the evaporator of a configuration pumped heat pipe recedes into the crevice, increasing the pumping pressure but decreasing

# ORIGINAL PAGE IS OF POOR QUALITY

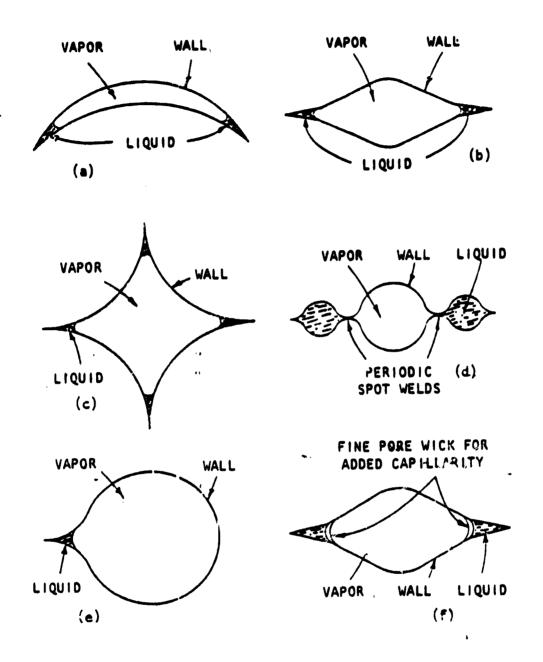
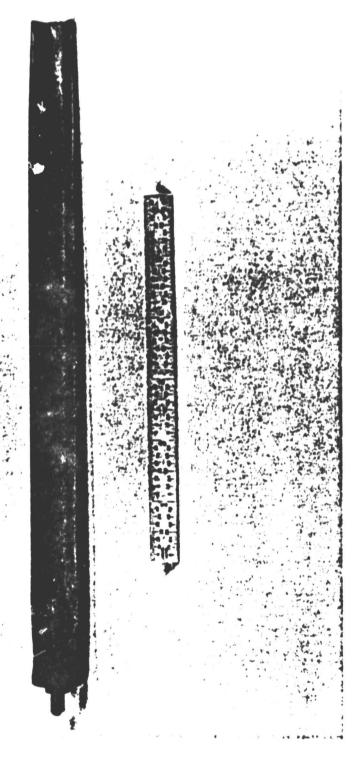


Figure 3'.3 Configuration Pumped Geometries

# ORIGINAL PAGE IS OF POOR QUALITY



Photograph of a Configuration Pumped Heat Pipe (Courtesy of U.S. Air Force)

FIGURE 3.4

the flow area. The inverse occurs in the condenser. This makes for a delicate tradeoff of liquid fill versus power handling capability. The problem is somewhat alleviated in the configuration/artery geometry of Figures 3.3d and 3.3f.

Configuration pumped heat pipes tend by their nature to have relatively low capillary pumping forces and low liquid drag. They therefore lend themselves well to consideration as elements in low temperature space radiators where large radiating areas require long heat pipes. The liquid inventory requirement of configuration pumped heat pipes appears to be comparable to that of the arterial structures discussed previously. The complete absence of conventional wicks is a substantial mass reduction. However, the non-round shapes are relatively poor pressure vessels so that the gain in mass due to elimination of the wick may be at least partially offset by a thicker wall requirement unless fluid vapor pressures are kept relatively low. Thus the operating temperature range for a configuration pumped heat pipe of low mass may be narrower than that for other geometries.

The ability of configuration pumped heat pipes to hold their shape is a function of the creep strength of the heat pipe envelope. Thermacore<sup>2</sup> previously identified the iron alloy, A-286, which exhibits an exceptionally high creep strength, and may well serve as a containment for configuration pumped heat pipes. (A-286 has a 0.1% creep at 1100°F in 10<sup>5</sup> hours under a 38,000 psi stress load).

# 3.3.3. Hybrid Wick/Pumped Heat Pipes

Since the dissipating capacity of a space radiator declines as the fourth power of any temperature loss, there is a strong incentive to minimize

temperature loss it incurs while moving large amounts of heat. This low AT operation is characteristic of vapor heat transfer. There may, therefore, be reason to make use of vapor heat transfer even at power levels which cannot be sustained by capillary pumping alone. Alternative or hybrid pumping means are possible and deserve consideration. This may be true not only for the radiators themselves, but also for the primary loops feeding them. A practical hybrid system may use an alternative pumping means for liquid transport over appreciable distances with capillary pumping for local distribution and collection.

The heat transfer capability of a conventional heat pipe can be limited by entrainment of liquid from the walls by the high velocity, counterflowing vapor. Separation of the liquid and vapor passages will permit greater heat flow under these conditions. Figure 3.5 is a hybrid system where the liquid and vapor flow are in the same direction. Therefore, the vapor shear forces may aid rather than inhibit liquid flow.

Hybrid heat pipes are directly analogous to two-pipe steam heating systems for buildings which use condensate pumps for liquid return. The principle has been extended to liquid metals by Philips Laboratories for use in Stirling engines.

The main disadvanges of the hybrid system are the increased probability of a leak at pump seals and joints and the dependence of operation on an external power source. For maximum redundancy, there should be a pump for each heat pipe, a serious penalty in complexity for a space radiator, making the approach seem more applicable to primary loops.

It may be possible to make use of the "heat of the raidator" to pump the liquid, much the same way that a capillary pump makes use of the "heat

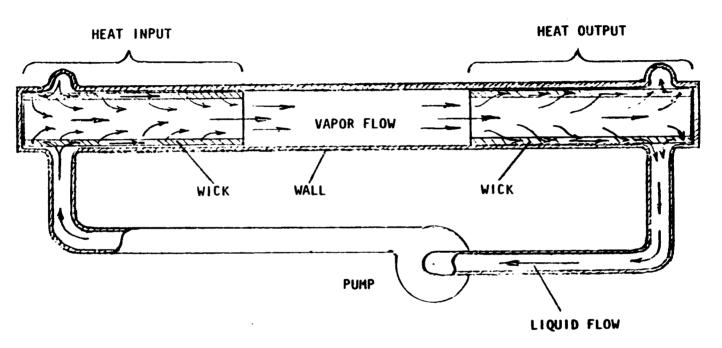


Figure 3.5 Mechanically Pumped Hybrid Heat Pipe

of the radiator."

Thermacore has recently begun the exploration of a "liquid piston pump" as part of its internal R&D effort. This pump uses a localized high heat flux, into the fluid, to develop a vapor bubble of sufficient pressure to push the liquid forward. Backward flow is prevented by the use of a check valve. A forward spring loaded valve allows the pressure at which the pump activates to be regulated.

Initial work to date has concentrated on gravity feed liquid systems with encouraging results. The extension of this concept to two phase systems with freedom from gravity will pose challenging work but may be worth a cursory investigation.

# 3.3.4. Other Concepts

There are numerous concepts which have been suggested as possible fluid pumping mechanisms for heat pipes and includes electro-magnetic, electrolytic, electrohydrodynamic and electrophoretic pumping. All of these are not suited for individual spacecraft radiator heat pipes. However, osmotic pumped heat pipes and artificial gravity are two possible mechanisms which are suited for spacecraft use.

If a spinning spacecraft can be so arranged that its centrifugal force will aid liquid return in heat pipes, it may be possible to eliminate pumping and depend entirely or predominantly on artificial gravity for this function. The result may be mass reduction (by wick elimination and, possibly, reduced fluid inventory) and an added degree of freedom in fluid selection (fluid need not have high surface tension).

Osmotic pressures can exceed capillary pressures by a factor of 100 to

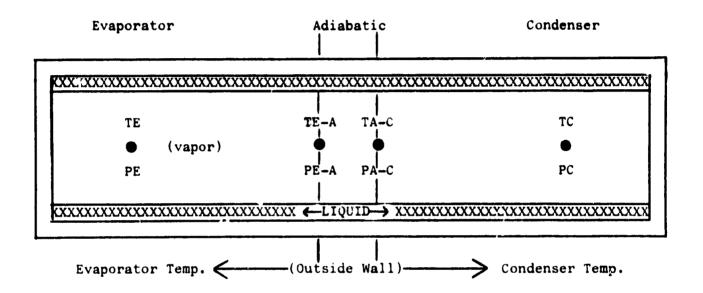
1,000. An osmotically pumped heat pipe is feasible in principle. Several designs have been proposed, but no hardware tests have been reported. The proposed designs all make use of gravity in one way or another: to keep liquid in place, to redistribute salt by natural convection, etc. It may be possible to devise a geometry which will function in gravity-free space. If so, osmotic heat pipes may avoid entirely the capillary limitations on available pumping pressure.

Flow rates through semi-per cable membranes are low; i.e., large areas are required to permit useful heat flow. There is, however, an interesting factor which may favor further consideration for low temperature space radiators. These radiators also require large areas because of the low radiant power densities. The osmotic process is such that the membrane must be located at the condenser (heat dissipating) end of the system, which is the radiating surface of a radiator. At temperatures below about 900°K, the power density from a black body radiator is less than the power density sustainable by flow of the best fluids (e.g. water) through membranes. That is, below this temperature the unit liquid flow rate through a membrane is more than sufficient to support the unit radiant heat load from a radiator of equal area, and a basic condition of successful operation has been satisfied.

The geometries considered to date are relatively massive, having two walls and a large liquid inventory. Membranes do not exist for operation above about 400°K. However, since an osmotic heat pipe would need no auxiliary power (comparable to a capillary heat pipe), it deserves further consideration.

# APPENDIX 1

This appendix has complete performance printouts of all the heat pipes tabulated in Section 3.1 and 3.2. The heat pipe program used is Thermacore's GROOVE27. Figure A.1 depicts the placement and definitions of many of the symbols in the printout.



DPVE = Pressure drop in vapor in evaporator

DPLEG = Pressure drop in liquid in evaporator grooves

DPUA = Pressure drop in vapor in adiabatic

DPLAG = Pressure drop in liquid in adiabatic grooves

DPVC = Pressure drop in vapor in condenser - (+) means drop, (-) means

recovery or increase

DPLGG = Pressure drop in liquid in condenser grooves

# APPENDIX 2

This appendix develops Equation 3.2 which shows how the mass of a radiator heat pipe increases with the performance. T of the heat pipe.

T = desired heat pipe temperature

ΔT = temperature drop down heat pipe

 $T = T_{\Omega} - \Delta T$ , actual heat pipe radiating temperature

 $A_0$  = radiating area of heat pipe at  $T_0$ 

 $A = A_0 + da$ , actual heat pipe radiator area required at T

Q = power to be radiated from heat pipe

da dt = increase in surface area decrease in temperature

$$\frac{da}{dt} = \frac{A - A_0}{T_0 - T}$$
 Eq. A.1

but

$$A = \frac{Q}{\varepsilon \sigma (T_0 - T) 4}$$

and

$$A_{O} = \frac{Q}{\varepsilon \sigma T_{O}^{4}}$$

therefore, with substitution into Equation A.1 and proper rearranging,

$$\frac{da}{dt} = \frac{A_0}{\Lambda T} \left[ \left( T_0 / T \right)^4 - 1 \right]$$
 Eq. A.2

Now, since area is a function of length, we have

$$d1 = 1_{e} [(T_{o}/T)^{4} - 1]$$
 Eq. A.3

where  $l_c$  = condenser lenth, but  $\frac{dl}{l_t} = \frac{dm}{m}$  where  $l_t$  = total heat pipe length, m = mass, we obtain with substitution and rearrangement -

$$dm = \frac{ml_{C}}{l_{t}}[T, T]^{4} - 1]$$
 Eq. A.4

which is Equation 3.2.

# REFERENCES

- 2. Garrett AiResearch, Study of a Space Nuclear Power System for a Nuclear Electric Spacecraft; JPL Contract 955008.
- 3. Thermacore, Inc., Letter Progress Report #3, October, 1978, Heat Pipe Heat Rejection System and Demonstration Model for the Nuclear Electric Propulsion (NEP) Spacecraft; JPL Contract 955100.

WALL MATL=30455 FLUID - RUBIDIUM EVAP TEMP - 434 GRAV ANG - 0.00 VAPOR DELTA-T - 50 DEG C WTG AMG - 0.00 DEG EVAP LENGTE 16-9291 IN 43-0000 CM ADB LANGTE 16-9291 IN 43-0000 CM COND LENGTH 69-7313 IN 176-0000 CM 43.0000 CH ORIGINAL PAGE IS OF POOR QUALITY TOTAL LENGTH 103-1500 IN 262-0000 CM 2.5400 CM 1.0 ) IN 0. D. 0.0762 CX WALL THERSE 0.0200 IN 0.0787 IN 0.2000 CM STOLY ZVOORD GROOVE REIGHT 0.0197 IN 0.050C CM LAND WIDTE 0.0344 IE 0.0875 CM 25 GROOVES (CLOSED) COVERED WITH 200 MESE

HO LIMIT EMCOUNTERED AT ----- 720 WATTS

----- TOTAL MASS = 1.749 EG

WANT PERFORMANCE DETAILS (Y OR M) ?T

PA-C PE PE-A PC DTHES/CH2 31291.9 30641.5 30261.1 29954.9 TT. TE-A TA-C DEG C 432.853 431. )48 430.502 431.72 EVAP TEMP COMD TEMP DELTA-T 431-139 434 2.56104 DPG = O DPC= 18214 DPC+DPG= 18214 DTHES/CH2 DPVE DPLED DPVA DPLAG 1030 180 305 1115 DPVC DPLCG -687 739

SOMIC LIMITS: EVAP- 2197 ADD- 2487 WATTS

Q/A'S= EVAP COND AXIAL VATTS/CM2
2 0 142
ERREYN EARLYN LIDREYN CAREYN CRRLYN

21 3244 109 3247 5

HOT FLUID CHARGE 129-61 GRAMS ROOM TEMP- VOLUME OF HOT FLUID CHARGE 84-6019 CM3

COLD FLUID CHARGE 151.635 3RAMS 98.9783 CM3

HEAF PIPE. (MESE) & 2 ENDCAPS 1596.9 GRANS

DELTA-T VALUES:

EVAP WALL EVAP LAG EVAP MASA EVAPORATION • 608936E-02 -300293 • 323831 -120554E-01 DEG C VAPOR (E) JAPOR (A) VAPOR (C) 1.3042 • 545898 -1.21729 CONDENSATION COND HESH COND LAG COND WALL ·0733*6*7 -147544E-02 -292101E-02 DEG C .20283

POWER OF 1775 WATTS CAUSES ----- ADB SONIC LIMIT

LAST HOM-LIMITED POWER CALCULATION WAS AT ----- 1750 WATTS

----- TOTAL DELTA-? = 7.16 DEG C

?

	•		4100 1000	W/ 125/ 10
FLUID = RUBIDIO EVAP TEMP = 30 GRAV AMG = 00	TH VALL M 77 VAPOR • 00 VW AN	ATL=30483 DELTA-T = 50 S = 0.00 DEG	D30 C	
			LaigiNA	L PAGE IS
ADR LEGITE	10-9291 IN A	3.0000 CK	URIGINA OF POO	R QUALITY
COID LEMOTE	00.2013 IN 17	610000 GM	UP PUU	K QUALITY
TOTAL LINGTH	103:1500 II 26	2:0000 CM		
O.D. NALL TEXESS GROOVE WIDTE	1.0000 III 0.0300 III	2-8400 CM 0-0762 CM		
GROOVE WIDTE	0.07 <b>87 IX</b>	0.2000 CH		
GROOVE HEIGHT LAND WIDTH	0:0197 IL	0.0500 CH		
25 GROOVES	(Crosed) COAFE	ED ALLE SOO WES	<b>X</b>	
NO TIMIL BECOM	ITERED AT	514	ATLE	
***************************************	OTAL DELTA-T =	6-44 DD C		
	OTAL NASS -	1.740 E		
WANT PERFORMAN	OF DETAILS IT O	R M) PT		
22	D Brok	PA-G	PC	DYE 16/CH2
9905.91	PB-A 6292.16	7774.0	8886-92	
•			•	
75 378.772	TB-A 367.761	74-0 364-907	70 370 <b>.856</b>	DED C
0,00,112	0010102	200,00	3101909	
EVAP PEMP 377	COND TENY 370-567	D <b>ZL7A-T</b> 6.44312		
DPC= 19141	DPG= O DP	C+DPG= 19141 D	yn 58/CH2	
		DPVA	DPLAG	
	132	517	821	
DPVC	DPLCG	•		
-1113	543			
	EVAP-			
₩A* 5=	EVAP	COND	MIAL	att2/ch2
	1	o	101	
E R REY#	E A REYM	LIG RET#	C A RET#	C R REY
10	2443	63	2456	3
HOT FLUID CHARE ROOM TEMP: VOL	E THE OF HOT FLUI	132.0 D CHARGE 96.17	19 GRAMS 41 CM3	
	NA			
COLD FLUID CHAI	98 • <b>9</b> 793 C			
HEAT PIPE. (NES	a) & 2 ENDCAPS	1596.9 GRAN	S	·
CELTA-T VALUES	1			
Z"AP VALL	2712 LeG	EVAP HESE	LVAPORATION • 600586	NIM A
	-1 100 105 06	10031 45-46		DEG U
7APOR (2) 3.01123	TAPOR (A)	VATOR (C)		
3.01123	2-35352	-5.9502		
•	•	•		
HOITASMICHOS -146734	-AESOSSE-AS	COND LAG	COND WALL	224 -
• T#0\ 9#	•00mm =00	• 1.40997 <b>-</b> 05	•101164	DEG C
POVER OF GOS	WATTS CAUSES	AD	B SONIC LINIT	
* LUM *** *****	UB BAILER 6:555			
LAUT HOL-LIMITY	ED POWER CALCUL.	TA CAU HUITA		CITTA 80
10				

7.34 DEG C TOTAL MASS = 7.34 DEG C

RUE COMDITIONS	38		4116 P.H.	3/22/79
FLUID - DOYTHI HTAP TEMP - 3 GRAV ANS - 0	EN A VALL ) 352 VAPOR 360 VTS AI	1471-30488 DELTA-T = 80 IG = 0.00 DE	D <b>26</b> C	
COED LING THE TOTAL LING TH	16-9391 IX (16-9391 IX (16-93913 IX 17 17 17 17 17 17 17 17 17 17 17 17 17	13.0000 CK 76.0000 CK 12.0000 CK		ORIGINAL PAGE IS OF POOR QUALITY
O BOOVE WIDTE O ROOVE REIGET LAED WIDTE	1.0000 IE 0.0300 IE 0.0787 IE 0.0286 IE 0.0287 IE 1 (CLOSED) COVE	0.2000 CM 0.2000 CM 0.0050 CM	SA	
EO LIMIT MCOU	TETERED AT	440	MATTS	
	MOTAL DELTA-T - MOTAL MASS -			
	ICE DETAILS (T)	•		
7%	73-1	PA-C	PC . 545105B+07	DATE CHS
TE 348-876	72-a 348-876	24-7 346-875	70 348-676	DEF C
<b>57AP TEMP</b> 382	COED TEMP 348-11	D <b>IL?A-?</b> 3 <b>.80</b> 9 <b>6</b> 9		
DPC= 3160	DPG= 0 DI	PC+D <b>PG= 316</b> 0	DYR ES/UAZ	
19	DPLEC 233 DPLCO 986	DPYA ?	DPLAG 1339	
SONIC LIMITS:	EVAP= 1	36626 ADD- 18	8 <b>977 WATTS</b>	
C/A' S=	EVAP 1	COND	AXIAL 68	VATTS/CM2
E R REY#	e a ret# 305	Lig Ret# 346	C A RETW aos	C R RETW
EOT PLUID CHAI ROOM TEMP. VOI	CE CULT TOE TO SKU		057 GP.1113 637 CH3	
CULD FLUID CHA	125-001 (			
JEAT PIPE, (NI	ESB) & 2 ENDCAPS	5 1610-42 GRA	МЗ	
DELTA-F VALUES	5 <b>t</b>			
E71P /ALL	EVAP LOS	EVAP NESH	EVAPORATION	ros e

-535963 1.34221 • 64413 •100098 DEG C 7APOR (2) TAPOL (A) 7APOR (C) .4882912-03 .4882812-03 .2441411-03 COND LAG COND WALL .131559 .131559 CONDENSATION COND MESH DEG C .2445571-01 -157453 -131558

POWER OF 650 WATTS CAUSES ----- CAPILLARY LIKET. DPL > DPV

LAST MON-LIMITED POWER CALCULATION WAS AT ----- 345 MATTS

```
6141 A.N. 3/23/79
BUM COMDITIONS:
FLUIL - DOWTHERM A
                    WALL MATL-30455
EVAP TEMP = 219
3 RAV ARS = 0.00
                     VAPOR DELTA-? - 50 DES C
                     476 AMG = 0.00 DED
EVAP LEMS TH 16.9291 IN
                         43.0000 CM
                                                     ORIGINAL PAGE IS
ADB LEMOTU 16.9291 IM
                          43.0000 CM
                                                    OF POOR QUALITY
COMD LIMOTE 69.2913 IE 176.0000 CM
TOTAL LIMOTE 103.1500 IM 262.0000 CM
               1.0000 IE
                           2.5400 CM
FRESHT LIAN
               0.0300 II
                           0.0762 CM
                           0.2000 CM
GROOVE WIDTH
               0.0747 11
S ROOVE MELT HO
               0.0256 IE
                           0.0460 CM
TWD AIDSE
               0.0247 IN
                           0.0627 CM
 27 GROOVES (CLOSED) COVERED WITH 200 MESE
HO LINIT MCCURTERED AT ------ 169 VATTE
JANT PERFORMANCE DETAILS (T OR M) 7T
              PE-A
                            PA-C
                                                         DYLES/CX2
                                           402432
 402517
               402492
                             402462
              73-A
                            7A-C
                                                         DEG C
 217.618
               217.615
                             217.612
                                           217.609
              COND TEMP
LVAP TEMP
                            DELTA-T
               217.271
                            1.72906
 219
                          JPC+DPG- 7261 DYMES/CM2
DPC= 7261
              DPG= 0
DPVE
              DPLES
                            DPVA
 24
               151
                             21
                                           808
              DPLCG
DPTC
 29
               619
SOMIC LIMITS:
                  EVAP- 15075 ADB- 17120 WATTS
Q/A'S=
              EVAP
                            COND
                                          AXIAL
                                                         WATTS/CH2
               ٥
                             ٥
                                           33
              E A REYS
                            LIQ RETO
                                          C A REY
                                                         C R REY
E R REY
```

325 42 325

HOT FLUID CHARGE 112.977 GRAMS ROOM TEMP. VOLUME OF NOT FLUID CHARGE 105.784 CM3

COLD FLUID CHARGE 133.501 GRAMS 125.001 CH3

HEAT PIPE. (MESH) & 2 EMDCAPS 1510.42 GRAMS

DELTA-T VALUES:

HEEK GAVE BOITAROGAVE EVAP WALL EVAP Log .228554 .780453 .27290? -100096 DEG C TAPOR (A) VAPOR (E) VARGR (C) .32136E-0J .292**9631-**02 . 2929692-02 CONDENSATION COND MESH COND Lag COMD WALL . 244657 E-01 .666662E-01 190864 .055916 DEC C

POGER OF 715 GATTS CAUSES ----- CAPILLARY LIMIT. DPL > DPV

LAST NOM-LIMITED POWER CALCULATION WAS AT ----- 710 WATTS

----- TOTAL DELTA-T = 5.37 DEC C ----- TOTAL MASS = 1.744 KG

Rue	COM	DIT	TOR	\$1
-----	-----	-----	-----	-----

FLUID - RUBIDIUM	VALL MATIMOOSS	
EVAP TEMP - 434	TAPOR DELTA-T = 80 DES C	
GRAY ANG - 0.00	W70 AM6 - 0.00 DEG	
EVAP LENGTE 16.92	1 IE 43-0000 CM	ORIGINAL PAGE 19
ADB LENGTE 15.92	1 IN 43-0000 CM	ORIGINAL THE
	3 IH 176-0000 CM	OF POOR OUALITY
TOTAL LANGTE 103-150		Of 100
Q.D. 1.00	O IX 2.8600 CH	
JALL THEMSE 0.03	0 IN 0.0762 CM	
OPOOVE WIDTE 0.10		
GROOVE MEIGHT 0.00		
LAED WIDTE 0.00		
25 GROOVES (CLOS.	D) COVERED WITH 200 MESE	

#### NO LIMIT ENCOUNTERED AT ---- 720 VATTS

107AL DELTA-7 = 2.43 DED C

# WART PERFORMANCE DETAILS (T OR E) ?T

7E 31296.2	PZ-A 30370.4	PA-C 30100-3	PC 30715-1	DYN ES/CM2
7E 432-861	78-4 431.242	7A-C 430-762	70 431 <b>.849</b>	DEG C
EVAP TEMP 434	COND TEMP 431-57	DELTA-T 2-42993		
DPC- 18214	D <b>7G</b> = 0	DPC+DPG- 18214	DTE ES/CM2	
DPVE 926 DPVC -615	DPLEC 1196 DPLCG 4900	DPVA 269	DPLAG 9336	
SONIC LIMITS:	STAP-	2314 ADB=	2631 VATTS	
Q/A'S=	EYAP 2	COND	AXIAL 142	VATTS/CH2
E R REY#	E A REY# 3161	LIQ RET# 92	C A REY# 3163	C R REY.

HOT FLUID CHARGE 92-1796 GRAMS ROOM TEMP. VOLUME OF HOT FLUID CHARGE 60-1694 CM3

COLD FLUID CHARGE 107-824 GRAHS 70-3814 CH3

HEAT PIPE. (MESS) & 2 ENDCAPS 1375-82 GRANS

#### DELTA-F VALUES:

.028031	evap laj •352\$; e=02	• 593373E-02	EVAPORATION -300293	DEG C
VAPOR (E) 1.61914	VAPOR (A) •479736	VAPOR (C) -1.08667		
COADENSACION .073367	COND MESH •143848-02	COMP Lag .35473E-03	COMD WALL - 202311	DES C

POWER OF 320 WATTS CAUSES ----- CAPILLARY LIMIT. DPL > DPY

LAST HON-LIMITED POWER CALCULATION WAS AT ------ 315 WATTS

TOTAL DELTA-T = 2.67 DEC C

RUM COMDITIONS			8124 A-M-	3/30/79
YLUID - RUBIDIO EVAP TEMP = 37 GRAV ANG - 0	7 VAPOR	NTL=30485 DELTA-	DEG C	
add length cond length	16.9291 IN 41 16.9291 IN 44 69.2913 IN 170 103.1500 IN 26	5.0000 CN 5.0000 CN	ORIG OF P	INAL PAGE IS
PARD AIDER SECOME BRIG. CHOOME AIDER	1.0000 IM : 0.0300 IE : 0.1063 IN : 0.0079 IE : 0.0079 IM : (CL)SED) COVER	0-2750 CM 0-0200 CM 0-0209 CM		
NO LINIT ENGOU	ITERED AT	814	vatts	,
•	OTAL DELTA-? = OTAL MASS =			
WANT PERFORMAN	CE DETAILS (Y O	R E) ?Y		
PE 9928-78	PE-1 8499-64	PA-C 8051-89	PC 9003•7	DTM ES/CM2
72 375.877		TA-C 366.486	TC 371.445	DES C
EVAP TEMP 377	COED TEMP 371-17	DELTA-T 5-82983		
DPC= 19139	DPG= O DP	C+DPG= 19139 D	THES/CH2	
DPVE 1429 DPVC -952	DPLEC 677 DPLCG 3599	DPVA 447	DPLAG 6867	
SONIC LIMITS:	EVAP-	790 ADB=	765 WATTS	
Q/A* S=	EVAP 1	COND	AXIAL 101	WATTS/CH2
E R RET#	E A RET# 2361	LIC REY#	C A RET# 2392	C R RET#
HOT FLUID CHAR ROOM TEMP. VOL	ge Une of hot flut		83 G <u>ram</u> 82 C <b>N3</b>	
COLD FLUID CHA	RGE 107-824 G 70-3814 C			
HEAT PIPE. INE	SE) & 2 ENDCAPS	1375.82 GRAM	S	
DELTA-T VALUES	t			
EVAP VALL • 015994	EVAP L4G -203109E-02	EZAM PAZA -350565E-02	EVAPORATION • 500488	DEG C
	VAPOR (A) 2.40698			
CONDERSATION •122278	00.1D MESS •8423392-03	COND L&G -500006E-03	COND WALL •151117	DEG C
POWER OF 64	5 VATTS CAUSES	AD	B SOUIC LIMIT	
LAST ROW-LINIT	ED POWER CALCUL	TA SAL LOITA		STIAN CA

------ TOTAL DELTA- F = 7.13 DEF C

7

MAN CONDITIONS	•		121 2 F.M.	3/20/79
FLUID = DOVTHE EVAP TEMP = 3 GRAV AMG = 0	RM A WALL N 52 VAPOR 500 WTG AM	ATL-30455 DELTA-T = 50 G = 0.00 DEG	•	
RVAP LENGTH	16.9291 IN 4	3.0000 C4	OR	IGINAL PAGE IS
add Ling th	16.9291 IN 4	3.0000 CM	OF	POOR QUALITY
COND LENGTY	69.2913 IX 17	6.0000 CM	σ.	•
TOTAL LEAGTE	103.1500 IN 26	5.0000 CM		
0 • D •	1-0000 IN	2-5400 CM		
VALL THANSS	0.0300 IX 0.1083 IX	0.0762 CH		
GROOVE WIDTE	0.1083 IN 0.0217 IN	0.2750 CM		
	0.0044 IN			
25 3 ROO YS3	(CLOSED) COVER	ED VITE 200 NES	in .	
KO LIHIT MICOU	RTEEND AT	440	VATTS	
	OTAL DELTA-T =			
VART PERFORMAN	CE DETAILS IT O	R M) TT		
PE •511061E+07	PE-A •511059E+07	PA-C •8110882+07	PC -5110 <del>54B+0</del> 7	DTEES/C%2
*E 344-591	75-a 344-391		TC 344-59	D773 C
EVAP TEMP 352	COND TEMP 342.773	DELTA=1 9-22729		
	DPG = O DP	C+DPG= 3294 I	OTH ES/CH2	
	DPLEG	DPVA	DPLAG	
18 DPVC	219 DPLCC	7	1430	
7	898			
SONIC LIMITS:	EVAP- 10	0576 ADB= 181	.288 VATTS	
Q/A* S=	EA7b	COND	AXIAL	WATTS/CH2
	1	0	86	
E R RETH	B A REY#	LIC REY#	C A RETA	C R REY
5	797	291	797	1
HOT FLUID CHAR	gr Whe of hot flui	120.2 D CHARGE 112.5	205 GRAMS 351 CM3	
COLD FLUID CHA	RGE 141-404 0 132-401 C			
HEAT PIPE. (NE	SH) & 2 ENDCAPS	1406.22 GRAN	13	
DELTA-T VALUES	:			
	EVAP 146 6-13104	.640463	HVAPORATION +100098	DEC C
VAPOE (2) •244141E=03	VAPOR (A) -C0=1141E=03	7AFOR (C) -244141E-03		
CONDENSATION • 244557 R= 01	1300 YESH • 1300 Y	ປະເທີ ໄປໄ 1.ລົປ40ສ	132076	peo c
	T & COOK	***************************************	-20601 G	JAT U
7012k of 87	5 VATTS CAUSES		APILLARY LIMIT.	ארה - שרת
LAST HOR-LINET	ED POSER CALCEL	IL SAN PCITA		ሃሃዕ ነፈ የሞል
	* 1-ATJEC JATO	11.92 020 0		

RUM COMDITION	l\$:		11:50 A	.N. 3/26/79
PLUID - DOWTH	IERM A	VALL MATLESCASS		•
RYAD TEMP =	219	VALL MATL=30485 VAPOR DELTA-T =	50 DEA C	
IRAY AMA	0-00	VAPOR DELTA-T = VID ANG = 0.00	DED	
-	0.00			ORIGINAL PLAT
EVAP LENGTH	16.9291	IN 43.0000 CN		
ADD LEED TH	16.9291	IN 43.0000 CH IN 176.0000 CH		OF POOR OF MALIT
COND LING TH	69.2913	IN 176-0000 CM		
POTAL LENGTH	103.1500	IN 262.0000 CM		
) • D •	1.0000	IN 2.8400 CM IN 0.0762 CM IN 0.2750 CM		
IALL TEXESS	0.0300	II 0.0762 CX		
HTGIV SVOOR	0.1083	IN 0.2750 CH		
ROOVE HEIGHT	0.0197	IX 0.0500 CM		
		IN 0.0125 CM		
25 G NOO VI	es (creard)	COVERED WITH 200	D MESE	
NO TIMES WHEE	//m #22## A		160 VARRE	
HO PINIT MEGG	ORIGINAL AT		TOP SELLE	
*********	TOTAL DELT	A-T = 3.55 D	B C	
		A-T = 3.56 DI = 1.535 EC		
P2070-1404C	TOTAL MASS			
WANT PERFORMA	TOTAL HASS	= 1.535 EG S (T OR E) ?T	<b>,</b>	DYN ES/CM2
MART PERFORMA	TOTAL MASS	= 1.535 g( S (T OR H) 77	<b>,</b>	DYN ES/CN2
VART PERFORMA PE 387562	TOTAL MASS LNCB DETAIL PE-A 387 538	= 1.535 EG S (T OR H) 77 PA=C 387503	PC 387479	
PE 387 562	TOTAL HASS LEGE DETAIL PE-A 387 556 TE-A	= 1.535 EG S (T OR H) ?T PA=C 387503 TA=C	PC 387479	
PE 387 562	TOTAL MASS LNCB DETAIL PE-A 387 538	= 1.535 EG S (T OR H) ?T PA=C 387503 TA=C	PC 387479	
PE 387 562  T3 216 - 152	TOTAL MASS LECE DETAIL PE-A 397538 TE-A 216.149	= 1.535 KG S (T OR H) 7T PA-C 387503 TA-C 216.146	PC 387479	
PE 387 562  T3 216 - 152	TOTAL MASS LECE DETAIL PE-A 397538 TE-A 216.149	= 1.535 KG S (T OR H) 7T PA-C 387503 TA-C 216.146	PC 387479	
WANT PERFORMA PE 387562 FX 216-152 EVAP TEMP 219	TOTAL MASS AMCE DETAIL PE-A 387538 TE-A 216.149 COMD TEM 215.446	P DELTA-T 3-56363	PC 387479 TC 216-143	
PE 387562  TE 216-152  EVAP TEMP 219	TOTAL MASS AMCE DETAIL PE-A 387538 TE-A 216.149 COMD TEM 215.446	= 1.535 KG S (T OR H) 7T PA-C 387503 TA-C 216.146	PC 387479 TC 216-143	
WANT PERFORMA PE 387562 FS 216-152 EVAP TEMP 219 DPC= 7307	TOTAL MASS AMCE DETAIL PE-A 387538 TE-A 216.140 COMD TEM 218.446	P DELTA-T 3-56363	PC 387479 TC 216-143	
WANT PERFORMA PE 3877562  TS 216-152  EYAP TEMP 219  DPC= 7307	TOTAL MASS AMCE DETAIL PE-A 387538 TE-A 216.149 COMD TEM 215.446	P DELTA-T 3.55363	PC 387479 TC 216-143	
VANT PERFORMA PE 3877562  IN 216.152  EVAP TEMP 219  DPC= 7307  DPVE 24	TOTAL MASS AMCE DETAIL PE-A 387538 TE-A 216.140 COMD TEM 215.446 DPG= 0 DPLES	P DELTA-T 3-56363  DPC+DPG= 7307	PC 387479 TC 216-143  PDYRES/CM2 DPLAG	
WANT PERFORMA PE 3877562  TX 216-152  EVAP TEMP 219  DPC= 7307  DPVE 24	TOTAL MASS AMCE DETAIL PE-A 387538 TE-A 216.140 COND TEM 215.445 DPG= 0 DPLES 179	P DELTA-T 3-56363  DPC+DPG= 7307	PC 387479 TC 216-143  PDYRES/CM2 DPLAG	
PE 387562  TS 216.162  EVAP TEMP 219  DPC= 7307  DPVE 24  DPVC 29	TOTAL MASS AMCE DETAIL  PE-A 387 538  TE-A 216.140  COMD TEM 215.446  DPG= 0  DPLES 179 DPLOS 736	P DELTA-T 3-56363  DPC+DPG= 7307	PC 387479 TC 216-143  7 DYKES/CN2 DPLAG 1200	DIG C
PE 387562  TX 216.162  EVAP TEMP 219  DPC= 7307  DPVE 24  DPVC 29  SOMIC LIMITS	TOTAL MASS AMCE DETAIL  PE-A 387 538  TE-A 216.140  COMD TEM 215.446  DPG= 0  DPLES 179 DPLOS 736	PA-C 387503  TA-C 216-146  P DELTA-T 3-56363  DPC+DPG= 730  DPVA 20	PC 387479 TC 216-143  7 DYRES/CN2 DPLAG 1200 - 16962 HATT	DIG C
PE 387562  TX 216.162  EVAP TEMP 219  DPC= 7307  DPVE 24  DPVC 29  SOMIC LIMITS	TOTAL MASS AMCE DETAIL PE-A 387536 TE-A 216.149 COMD TEM 215.446 DPG= 0 DPLEG 179 DPLCG 736 EVAP	PA-C 387503 TA-C 216-146 P DELTA-T 3-58383 DPC+DFG= 730' DPVA 20 AP= 14943 ADE=	PC 387479 TC 216-143 T DTRES/CN2 DPLAG 1200 - 16962 HATT	DIG C
PE 387562  TX 216.162  EVAP TEMP 219  DPC= 7307  DPVE 24  DPVC 29  SOMIC LIMITS	TOTAL MASS AMCE DETAIL  PE-A 387 538  TE-A 216.140  COMD TEM 215.446  DPG= 0  DPLES 179 DPLOS 736	PA-C 387503  TA-C 216-146  P DELTA-T 3-56363  DPC+DPG= 730  DPVA 20	PC 387479 TC 216-143  7 DYRES/CN2 DPLAG 1200 - 16962 HATT	DIG C
VANT PERFORMA PE 387562 TE 216-152 EVAP TEMP 219 DPC= 7307 DPVE 24 DPVC 29 SOXIC LIMITS:	TOTAL MASS AMCE DETAIL PE-A 387536 TE-A 216.149 COMD TEM 215.446 DPG= 0 DPLEG 179 DPLCG 736 EVAP	PA-C 387503 TA-C 216-146 P DELTA-T 3-56363 DPC+DPG= 7309 DPVA 20  AP= 14943 ADE COND	PC 387479 TC 216-143  PDYRES/CM2 DPLAG 1200  16962 MATT AXIAL 33	DMG C

 $\mathbf{C}$ 

HOT FLUID CHARGE 111-829 GRAMS ROOM TEMP. FOLUME OF HOT FLUID CHARGE 104-709 CM3

COLD FLUID CHARGE 131.942 GRAMS 123.541 GN3

HEAT PIPS. (NESH) & 2 EIDCAPS 1402-35 CRAMS

DELTA-T VALUES:

27AP VALL -228554	EVAP L&G 2.24923	EVAP NESH • 259345	EVAPORATION •100099	DEG U
VAPOR (E) -3210048-02	VAPOR (A) .292969E-02	VAPOR (C) •292969E-03	2	
CONDENSATION • 244557 E-01	COND MESE .6589721-01	COND L43 • 550474	COND WALL • Sõppese-01	DEC C
PCHER OF	559 WATTS CAUSES	*******	CAPILLARY LIMIT.	DPL > DPV

LAST NON-LIMITED POWER CALCULATION WAS AT ----- 553 WATTS

FLUID - RUBIDI	UN	WAL	L NATL-304SS		
EVAP TEMP -	134	VAP	DR DELTA-T	50 DEG	) C
GRAY ANG - C	.00	A 10	AMG = 0.00	DED	
BVAP LEEGTH	16.9291	IN	43.0000 CM		
ADB LENGTH	16.9291	IM	43.0000 CH		
COMD LINGTH	69.2913	LH	176-0000 CM		ORIGINAL PAGE IS
TOTAL LENGTH	103.1500	II	262.0000 CM		ORIGINAL FIXAL
		_			OF POOR QUAL
0 - D -	1.0000	IH	2.5400 CM		
JALL THEMSS	0.0300	IM	0.0762 CM		
GROOVE WIDTE	0.1083	IM	0.2750 CM		
3 ROOVE HEIGHT	0.0079	III	0.0200 CM		
LAND WIDTH	0.0079	II	0.0200 CM		
25 GROOVES	CLOSED	CO	VERED VITE 20	BEZK	

NO LINIT ENCOUNTERED AT ----- 720 WATTS

2.43 DE C ----- TOTAL DELTA-T = ----- TOTAL HASS -1.484 13

# WANT PERFORMANCE DETAILS (Y OR N) ?Y

PE 31296.8	9E-A 30 <b>3</b> 70-4	PA-C 30100-3	PC 30715-1	DTM ES/CM2
TE 432-861	78-4 431-242	7A-C 430-762	TC 431-849	DEG C
EVAP TEHP	COND TEMP 431.57	DEL TA-T 2-42993		
DPC= 18214	DPG= 0	DPC+DIG= 18114	DTM ES/CM2	
DFVE 926 DPVC -615	DPLES 1196 DPLCG 4900	DP <b>TA</b> 26 <del>9</del>	DPLAG 9336	
SONIC LINITS:	EVAP=	2314 ADB=	2631 VATTS	
J/A* S=	EVAP 2	COND	AXIAL 142	WATTS/CN2

92

LIO RET#

142 C A RET#

3163

C R REY

HOT FLUID CHARGE 92.1796 GRAMS ROOM TEMP. VOLUME OF HOT FLUID CHARGE 60-1694 CM3

COLD FLUID CHARGE 107.824 GRAMS 70-3814 CN3

E A REYS

3161

HEAT PIPE: (MSSR) & 2 ENDCAPS 1375-82 GRANS

#### DELTA-T VALUES:

A R REYM

21

STAP WALL	EVAP LGG •352612-02	27AP MESA • 593373E-02	EVAFORATION - 300293	DEG C
1FOR (E) 1.61914	VAPOR (A) •479736	VAFOR (C) -1.08667		
Loitazkatioa 702570•	COND MESH -145642-02	COND Lad •35473E-03	30MD WALL -202811	Dang C

POWER OF BECKETTS CAUSES ----- CAPILLARY LIMIT. DPL > DPV

LAST JON-LIGHTED POWER CALCULATION JAS AT -----STILK CLE

<sup>-----</sup> POTAL DELTA-T = 2.87 DH 0 = SZAK LATO7 ----1.404 .3

FLUID - RUBIDIT	JN.	ANTI	HATL-30	455			
EVAP TEMP - 3	7	TAPO	DE DELTA-	<b>?</b> =	30 DEG	C	
GRAT ANG - O	.00	R 40	ALC =	0.00	DEC		
EVAP LENGTE	16-9291	II	43.0000	CN			•
ADB LENG TH	16.9291	IX	43.0000	CN			
COND LING TH	69.2913	IH	176.0000	CM			ORIGINAL PAGE 19
TOTAL LENGTH	103-1500	IX	262.0000	CM			OF POOR QUALITY
O • D •	1.0000	IE	2.5400	CH			
SS.VIET LIAV	0.0100	II	0.025	L CM			
GROOVE WIDTE	0.1033	IM	0. 2750	CH			
GROOVE HEIGHT	0-0079	ш	0.0200	CM			
LAND WIDTE	0.0129	Ш	0.0326	CH			
			VERED VIT	E 200	) NESE		

# NO LIMIT ENCOUNTERED AT ----- 514 WATTS

TOTAL DELTA-7 = 4.56 DEC C O.601 EG

#### WART PERFORMANCE DETAILS (Y OR M) ?Y

PE 10019-5	P <b>I-A</b> 88 <b>48 - 97</b>	PA-C 8496-41	PC 9239• 51	DYN ES/CM2
TE 576-293	75-A 370.666	TA-C 3 <b>68</b> -84	TC 372.611	DEG C
EVAP TEMP 377	COMD TEMP 372.438	DELTA-T 4.56226		
DPC= 19133	DPG= 0	DPC+DPG= 19133	DYMES/CM2	
DPVE 1170 DPVC -745	DPLED . 876 DPLOG 3597	DP VA 363	DPLAG 6960	
SORIC LIMITS:	EVAP-	867 ADB=	876 VATTS	
Q/A*S=	EVAP 1	COND	AXIAL 101	JATTS/CM2
E R REY#	2 A RET# 2281	LIQ RET# 58	C A REY# 2290	C R REY

EOT FLUID CRARGE 95.35 GRANS ROOM TEMP. VOLUME OF BOT FLUID CHARGE 62.5663 CM3

COLD FLUID CHARGE 110-102 GRAMS 71-8683 CM3

HEAT PIPE, (NESH) & 2 ENDCAPS 580-457 GRAMS

#### DELTA-T VALUES:

EVAP VALL •201125	EVAP L3G -207981E-02	336022¥-02	EVAPORATION .5004d9	DAG	С
Vapor (E) 5.62695	VAPOR (A) 1-32544	VAPOR (C) -3.77051			
CONDENSATION .122278	HZZK CHOD 80-1802016.	COND LG • 5014491-03	COND VALL •492989E-01	D <b>T</b> C	C

POWER OF 710 WATTS CAUSES ----- ADS SONIC LIMIT

LAST NON-LIMITED POWER CALCULATION WAS AT ------ 705 WATTS

TOTAL DELTA-T = 6.12 DEG C

. CONDITIONS:

ORIGINAL PARE IS OF POOR QUALITY

L TREESS 0.0100 IM 0.0284 CM 0.0101 IM 0.0284 CM 0.008 IM 0.2750 CM 0.008 IM 0.0280 CM 0.008 IM 0.0280 CM 0.0080 CM 0.0084 IM 0.0240 CM

GROOVES (CLOSED) COVERED WITH 200 MESS

LIMIT EMCOUNTERED AT ----- 440 WATTS

---- TOTAL DELTA-T = 5.72 DE C
--- TOTAL NASS = 0.777 EG

#### T PERFORMANCE DETAILS (Y OR M) ?Y

3367 <b>4E+</b> 07	PE-A • 53387 2 E+07	PA-C -53387 E+07	PC •5338692+07	DYN ES/CH2
7 • 403	75-A 347.402	7A-C 347-402	TC 347•402	DEG C
P TEMP 2	COND TEMP 346.275	D <b>elta-</b> t 5.72485		
- 3206	DPG= 0	DPC+DPG= 3206	DYH E5/CM2	
E	DPLE 218	DPVA 6	DPLAG 1426	
3	DPLCG 894			
IC LINITS:	EVAP-	170527 ADB=	205679 VATTS	
' S=	EVAP 1	COND	axial 86	WATTS/CM2

FLUID CHARGE 123.66 GRAMS
4 TEMP. VOLUME OF HOT FLUID CHARGE 116.787 CM3

LIG RETA

297

C A REY

764

C R REY#

) FLUID CHARGE 142-992 GRAMS 133-888 CM3

E A REY#

764

? P! (MESH) 4 2 ENDCAPS 634.002 GRANS

#### TA-T VALUES:

REYM

' YALL '5328	3.70969	TVAP ALSH •611678	EVAPORATION •100098	DE C
)R (E) 35281E-03	VAPOR (A) -2441415-03	VAPOR (C)		
) ENSATION 14507 2-01	COAD MESH •149662	COND LAG • 909 <b>027</b>	COND WALL • 4301515-01	<b>ଅୟ</b> ୯

R OF 560 dates Sauses ----- Capillant Limit. DPL > DPT

<sup>&#</sup>x27; NON-LIMITED POWER CALCULATION WAS AT ----- 555 WATTS

FLUID = DOWTHERM A EVAP TEMP = 219 GRAV ANG = 0.00	WALL MATL=30485 VAPOR DELTA-T = 80 DED C WTG ANG = 0.00 DED
EVAP LIME TE 16-9291 ADB LIME TE 16-9291 COED LIME TE 69-2913 TOTAL LIME TE 103-1500	III 45.0000 CH ORIGINAL PARE 13 OF POOR QUALITY
0.D. 1.0000 WALL THEMSS 0.0100 GROOVE WIDTE 0.1063 GROOVE BEIGHT 0.0217 LAND WIDT: 0.0004 25 GROOVES (CLOSED	IN 0.0254 CM IN 0.2750 CM IN 0.0850 CM

NO LINIT ENCOUNTERED AT ---------- 160 WATTS

# WART PERFORMANCE DETAILS (Y OR M) TY

PE 396240	PE-A 396219	PA-C 396194	PC 396170	DTN ES/CH2
TE 217.008	7E-A 217.006	<b>1A-</b> C 217.003	TC 217.001	DEG C
ETAP TEMP 219	COMD TEMP 216.514	DELTA-1 2-48647		
DPC= 7280	DPG= 0	DPC+DPG= 7280	DYH ES/CM2	
DPVC 20 DPVC 24	DPLED 141 DPLCG 580	DPVA 17	92 <b>6</b>	
SONIC LINITS:	EVAP-	16500 ADB=	18735 /ATTS	
2∕7₄ 2≡	EVAP O	COND	AXIAL 33	WATTS/CH2
E R REYN	308 REY#	LIQ REY# 36	C A RET# 308	C R REYN
HOT PLUID CRAF			21.123 GRANS	

ROOM TEMP. VOLUME OF HOT FLUID CHARGE 113-411 CM3

COLD FLUID CHARGE 142-992 GRAMS 133.888 CN3

HEAT PIPE. (NESH) & 2 MIDCAPS 654.002 GRANS

DELTA-T VALUES:

3VAP WALL .7462415-01	2VAP L4G 1-55778	EVAP MESH -259088	Z7APORATION •100098	DE C
VAPOR (E) -27771E-02	VAPOR (A) -2441412-02	VAFOR (C) -2441416-0	2	
CONDENSATION •2445675-01	COND MESH -633176E-01	COND LAG -381132	COND WALL •132537E-01	DEG C
POWER OF 7:	15 VATTS CAUSES	*********	CAPILLARY LINIT.	DPL > DSA
LAST HON-LINI	TED POWER CALCU	LATION WAS AT		710 WATTS

TOTAL MASS = 0.06 DEG C

FLUID = MERCUE EVAP TEMP = 4 GRAV ANG = 0	Y WALL N 34 VAPOR •00 WTG AM	ATL=30458 DKLTA-T = 50 G = 0.00 DBG	DEG C	IIGINAL PAGE IS
ADS LEEGTE COMD LEEGTH	16-9291 IE 4 16-9291 IN 4 69-2913 IE 17 103-1500 IN 26	3.0000 CH 6.0000 CH	OF	POOR QUALITY
VALL THEESS GROOVE WIDTH GROOVE HEIGHT LAND WIDTH	0.3750 IE 0.0039 IX 0.0797 IR 0.0079 IE 0.0592 IX LOSED) COVERED	0-0100 CK 0-2000 CK 0-0200 CK 0-1504 CK		
	ETERED AT		VATTS	
	OTAL MASS =			
	CE DETAILS (T O			
PE • 386888 <b>E+07</b>	PB-A • 38 <i>6</i> 703E+07	PA=0 •386601E+07	PC • 386 <del>0</del> 7 <b>E+0</b> 7	DYN ES/CM2
TE 431-868	TE-A 431.839	TA-C 431.82	TC 431.833	, DMG C
ETAP TENP	COND TEMP	DELTA-T 2-88872		
DPC= 114106	DFG= 0 DP	C+DPG= 114106	DYN ES/CNS	
1547 DPVC	-	DPTA 1007	DPLAG 51200	
SONIC LINITS:	EVAP- 2	0097 ADS- 24	ettly 686.	
2/A* S=	ETAP 3	T COM D	AXIAL 1010	WATTS/CH2
E R REY#	E & RSY# 5074	LIG RET# 330	C A REY# 5074	C R REY#
ROOM TEMP. VOL	GE UMB of hot flui		91 GRANS 99 CN3	
COLD FLUID CHA	RG E 290.48 G 21.444 C			
HEAT PIPE. (ME	SH) & 2 ELDCAPS	158-596 GRAN	s	
DELTA-T VALUES	1			
SVAP WALL •284282	87AP L≤3 •732296	EVAP MESH 1.01444	SVAPORATION -100098	DEC C
VAPOR (E) •290527E-01	7APOR (A) •192871E-01	VAPOR (C) 129395E-01		
CONDENSATION 10-2758248.	-248109	.179159	COAD WALL .695914E-01	DEG C
POWER OF 93	5 WATTS CAUSES	CA	PILLARY LIMIT,	DPL > DPV
LAST NON -LINIT	ED POWER CALCUL	ATION WAS AI		930 VATTS
	OTAL DELTA-T = OTAL MASS =	3.44 DEG C 0449 4G		

PLUID	- MERCI	JRY	VAL	L HATL-30	<b>345</b> 5		
EVAP	TEMP -	352	TAR	OR DELTA-	7 -	50 DEG	C
G RAY	ANG -	0.00	A 40	ANS -	0.00	DEG	
EVAP	LEEG TE	16.9291	u	43.0000	CM		
ADB	LING TH	16.9291	II	43.0000	CM		
COED	LEGTE	69.2913	ш	176-0000	CM		
		4.00 4.000					

ORIGINAL PAGE IS OF POOR QUALITY

TOTAL LINGTE	103-1500	14 2	62.0000	CX
0.D.	0-3750	ш	0-9525	CM
VALL TREESS	0.0039	II	0.0100	CM
GROOVE WIDTE	0.0787	ш	0.2000	CM
GROOVE REIGHT	0.0079	IX	0.0200	CM
TWED AIDSE	0.0592	111	0.1505	CM
8 GROOVES (	CLOSED) CO	TELED	VITE 2	DO HESI

NO LINIT MCOUNTERED AT ----- 440 VATTS

TOTAL MASS = 0.440 EG

#### WART PRATORMANCE DETAILS (T OR M) TY

PB •1169022+07	PB-A •1167693+07	PA-C •1166392+07	PC •116691E+07	DYESS/CK2
73 350-588	72-A 350-437	7A-0 350-335	70 350∙3 <b>6</b>	D36 C
EVAP TEMP 352	COUD 1201P 350.023	DELTA-T 1.97729		
DPC= 120072	DFG= 0	DPC+DPG= 120072	DYN ES/CM2	
DPVE 1926 DPVC -434	DPL 25 4347 DPL C3 17798	DPVA 1313	DPLAG 32473	
SONIC LIMITS:	TVAP-	6206 ADB-	7012 WATTS	
Q/A* E=	EVAP 3	COM D	ATIAL 617	WATTS/CH2
E A REY#	E A RET# 3479	LIQ REY# 187	C A RET# 3480	CRREW 2

HOOT FLUID CHARGE CRANS FROM PEMP. VOLUME OF HOT FLUID CHARGE 20.8796 CMS

COLD FLUID CRARGE 290-5 GRAMS 21-4454 CHS

HEAT PIPE. (MESH) & 2 MIDCAPS 158-621 OPANS

#### DEL!A-T VALUES:

EVAP FALL	EVAP L.G •472935	evap mesa •654-18	2VAPORATION .100098	D20 C
7APOR (E) -150635	VAPOR (A) .102539	VAPOR (U) 336914E-0	1	
00ND2NUATION • 244357E=01	E23N 0100 e200c1•	00MD LUG •115693	COMD WALL •450586E-01	DEG C
BOUTE AR O	DE CARRO CARCO	·		991 - F7F

POWER OF DOS WARTS CAUSES ----- CAPILLARY LINIT, DPL > DPV

LAST ON-LIMITED FOUR CALCULATION WAS AF ----------- 300 WAFTS

140

FLUI	D - MERCI	URT	VALL NATL-30468
	TEMP =		TAPOR DELTA-T = 50 DEG C
O ILLY	ANG -	1100	2 10 ABS - 0.50 DES

ADB LENGTE COND LANGTE TOTAL LENGTE	16.9291 IN	43.0000 CH	ORIGINAL PAGE IS
	60.2913 IN	176.0000 CH	OF POOR QUALITY
	0.0000000	A 0804 6H	

0.D. 0.3750 IE 0.9524 CN
WALL THERSS 0.0039 IN 0.0100 CN
GROOVE WIDTH 0.0767 IE 0.2000 CN
GROOVE EXIGHT 0.0079 IN 0.0200 CX
LAND WIDTH 0.0592 IN 0.1504 CN
B GROOVES (CLOSED) COVERED WITH 200 MISSE

NO LINIT ENCOUNTERED AT ---- 264 WATTS

707AL DELTA-7 = 2.00 DEC C

#### WART PERFORMANCE DETAILS (Y OR E) ?T

PE 258510	<b>PE-A</b> 256701	<b>PA-</b> C 2537 <b>28</b>	PC 253630	DYN MS/CM2
TE 276.066	<b>15-4</b> 276-542	7A-C 275-168	70 276-15	D20 C
277 TEHP	COMD TEMP 274.921	DELTA-T 2.0791		
DPC= 127000	DPG= 0	DPC+DPG= 127000	DYN BS/CH2	
DPTE 2808 DPTC 98	DPLES 2705 DPLCS 11077	DPVA 1971	DPLAG 20211	
SONIC LIMITS:	EVAP-	1500 ADB=	1693 VAT 25	
Q/A' S=	ETAP 2	C KOO	ATIAL 370	VATTS/CH2
ERREY#	S A REY# 2436	LIQ REYN 105	C A RET# 2441	C R REY#

HOT FLUID CHARGE 284.166 GRAMS ROOM TEMP. VOLUME OF HOT FLUID CHARGE 20.9779 CH5

COLD FLUID CHARGE 290.48 GRANS 21.444 CH3

HEAT PIPE. (MESH) & 2 ENDCAPS 158-396 CRAMS

DELTA-T VALUES:

EVAP /ALL •116944	27AP L2G -3005 <b>57</b>	416008 • 416008	AVAPORATION . 100098	DEG C
VAPOE (E) •523926	VAPOR (A) •373779	VAPOR (C) •135647 Z=01		
CONDENSATION •244657E-01	COND RESE •101781	COND L.G •735424E-01	003D WALL -0861711-01	DEG C

POWER OF 310 WATTS CAUSES ------ CAPILLARY LIMIT, DPL > DPT

LAST ROM-LIMITED POWER CALCULATION WAS AN ----- BUS WATTS

RUM	COX	DIT	tor	15:

YLUID - DOUTER		VALL HATZ-304		
		MAR THE - O		
ETAP LENGTH ADD LENGTH COMD LENGTH	16-9 <b>291</b> 16-9291	IX 43.0000 IX 45.0000 IX 176.0000	CM CM	ORIGINAL PAGE IS OF POOR QUALITY
C.D. WALL THESS GROOVE VIDTH GROOVE REIGHT LAND VIDTH 12 GROOVES	0.0295 0.0045	1X 0.0127 1R 0.2750 12 0.0750	GM CM CM CM	

TOTAL MASS = 0.306 EC

# WANT PERFORMANCE DETAILS (Y OR E) TY

PE -474616E+07	7%-A -4747843+07	74-0 •4747698+07	PG •4747623+07	DYE E3/CH2
73 339.936	75-A 339.931	7A-0 339.9 <b>39</b>	70 339-9 <b>38</b>	D <b>E</b> C
EVAP TEMP 352	CORD TEMP 336.950	DELTA-T 15-0408		
DPC= 3430	DPG= 0	DPC+DPG= 3439	DTH ES/CH2	
DPYE 316 DPYC 68	DPLEG 220 DPLCG 903	DPTA 146	DPLAG 1330	
SONIC LINITS:	EVAP=	32664 ADB=	39214 VATTS	
3./ A* S=	<b>EVAP</b> 2	COND	AXIAL 347	VATTS/CH2
E R RET#	% 1 REY# 1656	LIG RET# 552	C A RET# 1656	C R RET#

ROT FLUID CHARDS
ROON TEMP. VOLUME OF NOT FLUID CHARGE 61.8192 CH3

COLD FLUID CHARGE 96-3628 GRANS 30-8641 CH3

HEAT PIPE. (MESH) & 2 ENDCAPS 219.701 GRANS

# DELIA-T VALUES:

175328	27AP Lub 10-462	EVAP NESE 1-33651	EVAPORATION •100093	DEA C
7APOR (2) +430483E=02	V&203 (A) -2137215-02	VAPOR (C) -7324222-03		
00NDMS10N • 2442 57 E-01	6010 .1288 -226322	004D 144 2.87392	004D VALL -433123E-01	D20 C

POYER OF 515 VATTS CAUSES ----- CAPILLARY LIMIT, DEL > DEV

LAST MORELIMITED POWER CALCULATION HAS AT ------ 510 MATTS

70 FAL DULTA-( = 17.42 DE 0 70 FAL MASS = 0.00 KG

17

2143 7.H. 3/27/79 RUM COMDITIONS: VALL HATL-30455 FLUID - DOWTEEN A STAT TEXT - 327 VAPOR DELTA-T = 50 DES C SHAT AND - 0.00 WYS AND - 0.00 DEG 16-9291 13 BYAP LEMS TH 43.0000 CM ORIGINAL PAGE IS 16.9291 IX LEMATE 43.0000 CM LDB COMD LING TH 60-2913 IN 176-0000 CM OF POOR QUALITY TOTAL LENGTE 103-1500 IE 262-0000 CM 1.2700 CH 0.5000 IX 0. D. 0.0080 IX WALL THEMSS 0.0127 CM GROOVE WIDTE 0-1085 IX 0.2750 CH 0.0660 CM 0.0286 II GROOVE ERIGET 0:0066 II 0:01@ CM LAND WIDTE 12 GROOTES (CLOSED) COVERED WITH 200 MESE NO LIMIT IMCOUNTERED AT 373 VATTE ------ TOTAL DELTA-? = 10.73 DM C TOTAL MASS -0.294 KG WANT PERFORMANCE DETAILS (Y OR M) ?Y PA-C DYE RE/CH2 PR-A -332065E+07 .3320373+07 -332091 B+07 ·3320471+07 73-A DES C TA-C 318.386 318.304 318.394 318-388 EVAP TEMP COMD TEMP DELTA-T 327 316-27 10.7302 DPC= 4112 DPG = 0 DPC+DPG= +112 DYNES/CH2 DPYE DPLX DPVA DPLAG 274 150 1722 283 DP7C DPLOG 103 1125 EVAP= 24880 AD= 29826 VATTS SOMIC LIMITS: Q/A' S= STAP COND AXIAL WATTS/CH2 294 2 ú E R RETA E A REY LIG RET# C A REYM C R REYS 405 1372 1272 4 ROY FLUID CHANGE 60.2462 GRAMS ROOM TEMP. FOLUNE OF BOT FLUID CHANGE 56.4103 CH3 COLD FLUID CHARGE 77.4415 GRANS 72.5108 CM3

HEAT PIPE, (MISH) & 2 DADCAPS 216.768 GRANS

DELTA-T VALUES:

EVAP WALL EVAP LIG EVAP MESE EVAPORATION 7.22392 -120098 DEC C .151407 1.13017 VAPOR (A) VAPOR (E) . 292969E-02 -1350133-02 ·3371092-02 COMDEMNATION COMD MESE SOND EAC COND WALL .2445*57* E-01 1.77523 - 27 5341 -372896E-01 DEC C POWER OF 121 VATTS CAUSES ----- CAPILLARY LIMIT. DPL > DPV LAST NON-LIKITED POFER CALCULATION WAS AT ----- 420 WATTS

TOWAL MASS = 0.234 M

```
FLUID - DOWTHERM A
                     WALL MATL-30483
                     VAPOR DELTA-T = 50 DER C
EVAP TEMP - 302
GPAT ANG - 0.00
                     VTS ANG - 0-00 DMS
EVAP LEGTH 16-9291 IN
                        43.0000 CM
                                                    ORIGINAL PAGE ID
ADS LEMOTE 16.9201 IE 43.0000 CM
COND LEMOTE 69.2913 IN 17.5.0000 CM
                                                   OF POOR QUALITY
TOTAL LENGTH 103-1500 IN 262-0000 CM
              0.5000 IN
                          1.2700 CM
0. D.
VALL TERESS
              0.0060 II
                          0.0127 CM
SHOOKS WIDTE
              0-1003 IE
                          0.2750 CM
             0.0236
SPOOVE REIGHT
                          0.0500 CM
              0.0076 11
                          0-0194 CM
LAND VIDTE
12 GROOVES (CLOSED) COVERED WITE 200 MESE
NO LIMIT MCOUNTERED AT ---- 318 VATTE
------ TOTAL DELTA-T = 8.36 DE C
      707AL HASS - 0.268 M
WANT PERFORMANCE DETAILS (T OR M) TY
                                         PC
                           PA-C
                                                       DYE ME/CH2
                           .222821 5+07
 .222571+07
              -222542I+07
                                          .222506E+07
              TE-A
                           TA-C
                                                       D20 C
 205.297
              298.279
                            295.274
                                          290.271
              COMD TEMP
EVAP TEMP
                           DELTA-T
              203 - 623
                            8.37695
 302
             DPC - 0
DPC= 4834
                         DPC+DPG- 4834 DYMES/CM2
DPYS
              DPLSI
                           DPVA
                                         DPLAG
              308
                            163
                                          1955
 280
              DPLCG
DPTC
150
              1252
SONIC LIMITS.
             EVAP= 17710 ADB= 20631 WATTS
4/A*5=
              EVAP
                           COND
                                         AXIAL
                                                       WATTS/CH2
              1
                                          244
E R REYS
              U A RETA
                           LIG REY
                                         C A REY#
                                                       C R RETA
              1151
                            233
                                          1151
HOT PLUID CRASCE
                                    57.6718 GRAMS
ROOM TEMP. VOLUME OF LOT FLUID CHARGE 63.3668 CM3
COLD FLUID CHARGE 72.9808 GRAKS
                 60.3341 CM2
HEAT PIPE. (MESH) 4 2 MIDCAPS 214.816 GRAMS
DELTA-T VALUES:
ETAP WALL
             EVAP LOG
                          EVAP MESH
                                         BVAPORATION
.130299
             5.52068
                            .362:60
                                                        DEG C
                                         ·100 098
VAPOR (E)
             7APOR (A)
                           VAPOR (C)
 .756836E-02
             -484281E-02
                           •366211E=02
RESH CHO HOMESH
                           COND Las
                                         LIAV GROD
 .2145372-01 .235245
                           1.35508
                                         •032033
                                                        DEG C
POYER OF
          375 MATTS CAUSES ----- CAPILLARY LIMIT. DPL > DPY
LAST HON-LIMITED POWER CALCULATION MAS AF -----
                                                   370 JATES
----- TOTAL DELFA-F -
                             9.32 DEG C
TOTAL MASS
```

0.288 KG

RUM CONDITIONS	10		2124 P.H.	3/27/79
FLUID - DOWTER EVAP TEMP - 2 GRAV AND - 0	TRH A WALL I	MATL=30458 DELTA-T = 80 EC = 0.00 DE	DEG C	
COMD LINGTH	16-9291 IN ( 16-9291 IN ( 69-2915 IN 17 103-1600 IN 20	76.0000 CM	ORIC OF I	NAL PAGE IS
GROOVE REIGHT LAND VIDTE	0-0007 II	0.2780 CM 0.0880 CM	SE .	
		264	VATTS	
	OTAL MASS -	6-40 DE C 0-201 EG		
78	7E-A -1398898+07	PA-C •1308678+07	PG • 1398462+07	JTH 201/CH2
75 271-81	TE-A 271.790	74-0 271-791	TC 271.786	D.23 C
EVAP TEMP 277	COND TEMP 270-511	DELTA-T 6-48877		
DPC= 5568	D20= 0 D1	PC+DPG= 5568	OTH ES/CH2	
DP Y Z 289 DP Y C 208	DPL 25 351 DPL 05 1436	DPVA 193	DPLAG 2298	
SONIC LIMITS.	27AP- 2	11918 ADS- 1:	3775 WATTS	
4/4' S=	EVAP 1	O COM D	AXIAL 208	VATTS/CH2
3 R Rey♥ 3	e a reta 966	lig reyn 194	0 A 7 BT# 965	C R REY#
HOT FLUID CHAR HOOM TEMP. VOL		65-11 (D CHARGE 51-66		
COLD FLUID CHA	INGS 68-5201 0 54-1575 (			
HEAT PIPE. IME	SH) 4 2 ENDCAPS	212.537 GRAI	48	
DZLTA-T VALUZS	:			
ETAP WALL -111323	LTAP L.S 1-16533	•310 <b>547</b>	IVAPORATION •100098	DIG C
71POR (E) •1098632-01	#AFOR (A) -786830E-02	7APOR (C) • 132422E-02		
Jon Dali Sation - 24-1567 2-01	-19857	20ND Lag 1-02 <b>143</b>	COND HALL -273353E-01	DEG C
DOWER OF 31	O WATES CAUSES	ansamenen j	CPILLAST LIMIT.	DPL > DPY
THEEL FOR TURE	ED POWER GALGUE	Lation las at	3	OS WATTS
	OYAL DELTA-T = CLAR LANC	7.48 DES C 0.231 KG		

MINUTE - DOWTHERN A VALL HATL=30455 EVAP TEMP - 252 VAPOR DELTA-T - 50 DEG C GRAT ANG - 0.00 WTG AMG = 0.00 DMG ORIGINAL PAGE IS EVAP LIMOTE 16.9291 IE 43.0000 CM ADB LIMOTH 16.9291 IE 43.0000 CM COND LIMOTH 69.2913 IN 176.0000 CM 43.0000 CM OF POOR QUALITY TOTAL LINGTH 103-1500 FE 262-0000 CM 0.D. 1.2700 CM 0.5000 IM 0.0050 IN VALL TREESS 0.0127 CM 0-1003 IE 0.2750 CM GROOVE WIDTH GROOVE MEIGHT 0.0197 IN 0-0500 CM

0.0247 CM

TO LINIT MCOUNTERED AT ---- 219 WATTS

TOTAL DELTA-T = 4.98 DE C

0.0097 IX

12 GROOVES (CLOSED) COVERED WITH 200 MESE

HTGIV GEAL

#### WART PERFORMANCE DETAILS (Y OR M) TY

PE 8 <b>3779</b> 3	P <b>E-A</b> 63 <b>7 48</b> 5	PA=C 837235	PC 836952	DYERS/CK2
TE 248 • 035	TB-A 248.017	74-0 246-004	70 247-998	DED C
EVAP TEMP 262	COND TEMP 247.018	DELTA-7 4-96198		
DPC= 6311	DPG= 0	DPC+DPG= 6311	DTEES/CH2	
DPTE 307 DPTC 243	DPLES 413 DPLCS 1693	DPTA 231	DPLAG 2761	
SONIC LINITS:	SVAP=	7617 ADB-	8733 VATTS	
7/4° S=	ETAP 1	COND	AKIAL 172	SKOVETTAV
E R RET#	5 A RSY# 806	LIQ REY# 131	C A REY# 806	C R REY#

HOT FLUID CHARGE 52.5251 GRAMS ROON TEMP. VOLUME OF HOT FLUID CHARGE 49.1836 CM3

COLD FLUID CHARGE 64.0595 GRAMS 59.9808 CH3

HRAT PIPE. (MESH) & 2 ENDCAPS 209.931 CTANS

DELTA-T VALUES:

EVAP VALL •94.753E-01	E7AP LUG 3-09005	EVAP MESH •331114	EVAPORATION .100098	DEG C
7APOR (E) -172119E-01	VAPOR (A) •1318362-01	VAFOR (C) •148926E-01	ı	
CONDENSATION • 244567 E-01	.166508	008D L.G •75716	COND WALL • 230995E-01	DEG C
POWER OF 24	45 VATTS CAUSES		CAPILLARY LINIT.	DET > DEA
LAST HOM-LIHI	NULLAD REPOR DEL	LAPION VAS AT		40 VAITS

TOTAL BASS - 0.274 KG

RUM COMDITIONS	31		2: 4 P.H.	3/27/79		
PLUID - DOYTHI EVAP TEMP - 2 GRAV AMG - 0	219 VAPGE	MATL=30435 DELTA=7 = 50 M = 0.00 DR				
ADB LEGGTE	16.9291 IN 6 16.9291 IN 6 69.2913 IN 17 103-1500 IN 26	43-C000 CM	·	ORIGINAL PAGE IS OF POOR QUALITY		
O.D. VALL THEESS GROOVE WIDTH GROOVE HEIGHT LAND WIDTH		1.2700 CH 0.0127 CH 0.2750 CM 0.0800 CM 0.0247 CM				
	(CLOSED) COVE	RED VITE 200 NE	SE.			
HO LINIT MECO	DETERED AT	169	VATTS			
	rotal delta-t = rotal hass =	4.05 DEG C 0.274 EG				
VALT PERFORMAL	ICE DETAILS (T	OR A) ?T				
PE 384484	P <b>E-A</b> 384095	PA-C 383751	PC 383 <i>2</i> 96	DTH ES/CH2		
TE 215-845	<b>71-1</b> 215-805	7A-C 215.771	70 215-724	DEG C		
EVAP TEMP 219	COND TEMP 214-952	DELTA-7 4-04829				
DPC= 7317	DPG= O	PC+DPG= 7317	DTN 25/CH2			
DPTE 388 DPTC 465	DPLES 375 DPLCS 1536	DPTA 334	DPLAG 2505			
SONIC LIMITS:	EVAP=	3713 ADB=	4207 WATTS			
Q/A' S=	EVAP O	COND	AXIAL 133	VATTS/CH2		
ER REY# 2	E A REY# 643	LIQ REY# 76	C A RET# 543	C R RET#		
HOON TEMP. VOI	RGE LUME OF HOT FLU	-	219 Grams 887 CN3			
COLD FLUID CHARGE 64.0595 GRAMS 59.9908 CM3						
HEAT PIPE. (MESH) & 2 ENDCAPS 209.931 GRANS						
DELTA-T VALUES:						
3746241E-01	EVAP L&G 2.44127	•53893	EVAPORATION •100093	DEG C		
VAPOR (E) .398712E-01	71POR (1) •344238E=01	7APOR (C) •4663095-01				
CONDENSATION • 244557 E=01	-131746	COND LCG -397897	COND WALL •018292	DEG C		
POWER OF 220 WATTS CAUSES CAPILLARY LIMIT: DPL > DPV						
LAST HOH-LIHI	PED POWER CALCU	- 14 CAN ROLTAL		215 JATTS		
	TOTAL DELTA-P = SARA LATOR					

RUE COMDITIONS	3 e		9136 A.H.	3/30/70
FLUID - MERCUI	ey VALI	NATI-304SS		
EVAP TEMP -	ISA YAR	R DELTA-T = 50	DEG C	
GRAY ANG -	0.00 VTG	l nati-304SS Dr drita-t = 30 Ang = 0.00 di	B	
	4.4 0005 19	48 4040 AV		ODICINAL DACE IS
ETAP LEGITE	10.0291 18	43.0000 CM		ORIGINAL PAGE IS
ADD LENG 711 COND LING TH	60.2013 IN	176-0000 CM		OF POOR QUALITY
TOTAL LEEGTH	103-1500 IK	202.0000 CM		
O.D.	0.2500 IE	0.6350 CM		
WALL THENSS GROOVE WIDTH GROOVE REIGHT LAND WIDTH	0.0025 IN	0.0064 CM		
GROOVE FIDTH	0.1083 IK	0.2740 CM		
CROOVE REIGHT	0.0079 14	0.0200 CN		
LARD VIDTO	######################################	HEIM OOS HILV CZ		
S GROOTES II	PROPERTY COLET	D WITH AUU MASS		
NO LINIT EECO	MITERED AT	720	VATTS	
	T-ATIED LATO	- 4-13 025 (	3	
	TOTAL NASS	- 4.13 DE 0		
		•		
WART PERFORMAN	ICE DETAILS ()	7 OR N.) 74		
WART PERFORMAN		-		
		-	PC	DYN <b>25</b> / GM2
		PA-G -379924E+07	PC •3603082+07	DYN ES/CM2
PE .3815@E+07	PB-A • 360703 E+07	PA-C • 379924E+07	•	
PE .3815@E+07	PB-A • 360703 E+07	PA-C • 379924E+07	•	DYN E6/CM2
PE .3815095+07 12 430.875	PB-4 .360703D+07 TE-A 430.712	PA-C -379924E+07 TA-C 430-564	•	
PE .3815095+07 12 430.875	PB-4 .360703D+07 TE-A 430.712	PA-C -379924E+07 TA-C 430-564	•	
PE .3815@E+07	PB-4 .360703D+07 TE-A 430.712	PA-C -379924E+07 TA-C 430-564	•	
PE .3818695+07 TE .450.875 EVAP TEMP .454	PE-4 .360703E+07 TE-A 430.712 COND TEMP 429.872	PA-C •379924E+07 TA-C •30•566 DELTA-T ••12042	TC 430-637	
PE	PE-A .360703D+07 TE-A 430.712 COND TEMP 429.672 DFG= 0	PA-C -379924E+07 TA-C 430-564	TC 430-637	
PE	PE-A .360703D+07 TE-A 430.712 COND TEMP 429.672 DFG= 0	PA-C -379924E+07 TA-C 430-564 DELTA-T 4-12042 DPC+DPC= 114159	TC 430-637	
PE	PE-A .360703D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 DPLEG 7271	PA-C •379924E+07 TA-C •30•566 DELTA-T ••12042	TC 430-637	
PE	PE-A .360703D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 DPLEG 7271	PA-C 379924E+07 TA-C - 430.564 DELTA-T - 4.12B42 DPC+DPG= 114169 DPVA	TC 430-637  DYN ES/CM2  DPLAG	
PE	PE-A .360703D+07 TE-A 430.712 COND TEMP 429.672 DFG= 0	PA-C 379924E+07 TA-C - 430.564 DELTA-T - 4.12B42 DPC+DPG= 114169 DPVA	TC 430-637  DYN ES/CM2  DPLAG	
PE	PE-A .360703 D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 OPLEG 7271 DFLCG 29763	PA-C 379924E+07 TA-C 430-564 DELTA-T 4-12942 DPC+DPG= 114159 DPVA 7766	DYNES/CH2	
PE	PE-A .360703 D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 OPLEG 7271 DFLCG 29763	PA-C 379924E+07 TA-C - 430.564 DELTA-T - 4.12B42 DPC+DPG= 114169 DPVA	DYNES/CH2	
PE	PE-A .360703 D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 OPLEG 7271 DFLCG 29763	PA-C -379924E+07 TA-C 430-564 DELTA-T 4-12942 DPC+DPG= 114169 DPVA 7766	TC 430-637  DTH ES/CH2  DPLAG 56688	
PE	PE-A .360703 D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 OPLEG 7271 DFLCG 29763	PA-C 379924E+07 TA-C 430-564 DELTA-T 4-12942 DPC+DPG= 114169 DPVA 7766	DYNES/CH2	DEG C
PE	PE-A .360703 D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 OPLES 7271 DPLCO 29763 EVAP	PA-C -379924E+07 TA-C 430-564 DELTA-T 4-12942 DPC+DPG= 114169 DPVA 7766	TC 430-637  DTH ES/CH2  DPLAG 56688  LOGG WATTS  AXIAL	DEG C
PE .381569E+07  TE .450.875  EVAP TEMP .456  DPC= 114169  DPVE .8650 DPVC .3844  SOMIC LIMITS: 2/A'S=	PE-A .360703 D+07 TE-A 430.712 COND TEMP 429.872 DFG= 0 DPLEG 7271 DPLCG 29763 EVAP=	PA-C 379924E+07 TA-C 430-564 DELTA-T 4-12942 DPC+DPG= 114169 DPVA 7766	DTHES/CH2 DPLAG 56688 LCO69 WATTS AXIAL 2273	DEG C

HOT FLUID CHARJE 206.063 GRANS COON TEMP. VOLUME OF HOT FLUID CHARGE 15.2117 CX3

COLD FLUID CHARDE 213.035 GRANS 15.7268 CH3

HEAT PIPE. (MESH) & 2 ENDCAPS 76.483 GRANS

DELTA-T VALUES:

.270618	EVAP Lug 1-19874	1.554a7	EVAPORATION .100098	DEC	c
**************************************	74.07 (A) 742.744	7AFOR (C) 725098 2-01			
Condensation - 244557 E-01	BZK GZOS e13085.	00ND 11.4 • 1934 <b>3</b> 9	COND WALL .063033%-01	DEE	3

POADS CF 775 MATTS CAUSES ----- CAPILLARY LIMIT. DPL > DrV

LAST NON-LIMITED POYER CALCULATION YAS AT ----- 770 MARTS

AUR CORDITION	,,		DIAG TOUS	3/30/19
FLUID - MERCUI	Y VALL	MATL=304SS DELTA-T = 60		
GRAV ANG = (	LOZ TAPOR	MG = 0.00 DE	DEG C	
EVAP LEMOTE	16.9291 IX	43-0000 CH		ORIGINAL PAGE IS
adb leigth	16.9291 II	43-0000 CM	(	ORIGINAL TAGE
COND LINGTE	69.2913 IN 1	76-0000 CM	ı	OF POOR QUALITY
TOTAL LINGTE	103-1500 IK 2	62.0000 CM		
D.	0.2500 IX	0-6350 CM		
.ALL THEMES	0.0025 IX 0.1063 IX	0.0064 CM		
GROOVE WIDTH	0-1083 IE	0.2750 CM		
GROOVE HEIGHT	0.0079 IX 0.0718 IX	0.0200 CM		
4 GROOVES (C	COARD) COARED	VITE 200 MESE		
HO LINIT ENCOU	MITERED AT	598	VATTS	
***************	POTAL DELTA-T =	3.62 DE C		
***************************************	TOTAL MASS =	0.281 EG		
WANT PERFORMAN	ICE DETAILS (Y	OR M) ?Y		
PE	DECA	PA-C	PC	DTM ES/CM2
739459E+07	2385353+07	PA-C -23768614-07	2380273+07	DIRBOTORE
TE	TE-A	TA-C 398.924	TC	DMG C
399.401	399 • 153	398-924	399-016	
	COMD TEMP			
402	398-379	3-62061	•	
BBC 41 <i>63</i> 04	D <b>29</b> - A B	PC+DPG= 116291	<b>DEW</b> 50 4040	
Dica 116581	D10= 0 D	POTUPUE 110291	DIR ES/CR2	
DPVE	DPLEC	DPTA	DPLAG	
9242	7655	8462	59687	
DPVC	DPLCG	-		
-3408	31338			
SONIC LIMITS:	EVAP=	5424 ADB=	6418 WATTS	
Q/A'S=	EVAP	COND	ATIAL	WATTS/CM2
	6	1	1888	
		_		
E R REY#	E A REY#	LIQ REY#	C A RET#	C R RETA
11	6726	397	6729	2
_				-
HOT FLUID CHAI	RG B	187.	61 GZANS	
		ID CHARGE 13.8	499 CN3	
•				
CCLD FLUID CHA	LAGE 193.515	G RANS		
	14.2858			
	•			
HEAT PIPE, IN	ESII) & 2 EMDCAP	S 87.8669 GRA	MS	
DELTA-T VALUES	S <b>:</b>			
EVAP WALL	EVAP L&G	evap nesh	EVAPORATION	
7.29854	•950525	1.31773	• 1000 <b>38</b>	DRC C
VAFOR (2)	(A) EOGAV	7APOR (C) 917969E-01		
-248291	.223004	917969E-01		
,	•			
COIDENSATION	COMD MESE	COND Lag	CCID AYTT	
.24557E-01	-322469	.232703	.5023945-01	DEG C
POWER OF 6	L5 YATTS CATSEC	()	APIELANT LIMITA	DPL > DP7
LAST MOM-LINI	FED POVER GALCU	Lation was at -		610 WATTS

TOTAL DELTA-T = 3.69 DEG 0

The contract of the contract o

RUM COMDITIONS	11		9152 A.H.	3/30/79
FLDID - MERCUS STAP TEMP - 3 GRAY AND - 0	M VAL 142 VAP 0-00 VTS	L HATE-BOAS 3 OR DELTA-T - 50 AMS - 0.00 1	DEC C	
AVAP LING TE ABB LING TE CORD LING TE TOTAL LING TE	16.9291 IX 69.2913 IX	43.0000 CM 176.0000 CM		ORIGINAL PAGE IS OF POOR QUALITY
O.D. VALL TREUSS 6 MOOVE VIDTE 6 MOOVE HEIGHT LAND VIDTE 3 GROOVES ((	0.0025 IN 0.1083 IZ 0.0079 IX 0.1318 IN	0-0200 CM	ı	
NO LINIT ENCO	MTERED AT		O VATES	
	TOTAL MASS	- 3.30 DBS - 0.273 EG	<b>0</b>	
PE •1162625+07	PB-A •1181863+6	24-4	P6 •1144383+07	DYRES-OR2
TE 350.04	78-4 340-583	<b>540.046</b>	TG 340-179	<b>365</b> C
EVAP TEMP 352	COND TEMP 348-699			
DPC= 120118	DPG= 0	DPC+DPG= 120116	DTN ES/CM2	
DFYE 10774 DPYC -2506	DPLES 7684 DPLCG 31464	DPVA 10121	DPLAG 59918	
SOLIC LIMITS:	BVAP-	2622 ADB=	2921 VATTS	
Q/A* 5=	evap 5	COM D	AX IAL 1389	VATTS/CM2
e r Cata 9	8 A REY# 5337	LIG REY# 372	C A REY# 5345	C R RET#
ROOM TEMP. VO		166 ZUID CHARGE 12	0-292 GRAMS 4976 CM3	

COLD FLUID CHARGE 173.995 GRAMS 12.8448 CM3

EEAT PIPE. (MESH) & 2 ENDCAPS 99.2507 GRANS

DEL PA-T VALUES:

. 175328	EVAP LAI .680505	1.00319	evaporation •1000s8	9 <b>26</b> C
V1POR (E) •407031	7APOR (A) •537354	VAPOR (C) 133057		
CONDENSATION • 244557 E-C1	00.1D MESE •215535	00%3 Lag •168603	COND YALL • 429384E-01	DEG C
SOMEM OF	50 WATTS CAUSE	S	CAPILLARY LIHIT.	DPL - DPT
LAST YON-LINI	TED FOVER CALC	TA SAU KOITAJU		A5 VATTS
	TOTAL DELTA-P		c	

:5

 VAP
 LENG TH
 16.9291
 IM
 43.0000
 CM

 DB
 LENG TH
 16.9291
 IM
 43.0000
 CM

 OHD
 \* NG TH
 69.2913
 IM
 176.0000
 CM

 \*\*OTAL
 AG TH
 103.1500
 IM
 262.0000
 CM

43.0000 CH ORIGINAL PAGE IS 43.0000 CH OF POOR QUALITY 0.6360 CH

NO LINIT ENCOUNTERED AS ----- 316 VATTS

------ TOTAL DALTA-T = 4.51 DE C

#### JANT PERFORMANCE DETAILS (T OR M) ?T

PE 445637	PS-A 432020	PA-C 418926	PC 41 <del>99</del> 52	DYNES/CH2
TE 300.518	TE-A 209.124	ta-c 297 • 7 <b>4</b> 7	10 297.456	DEC C
SOS END	COND TEMP 297 • 493	DELTA-1 4-50708		
DPC= 124573	DPG= 0	DPC+DPG= 124573	DYNES/CH2	
DPVE 13616 DPVC -1027	DPLEG 5634 DPLCG 23093	DPVA 13092	DPLAG 43953	
SONTA LIMITS:	EVAP-	1062 ADB=	1146 VATTS	
3/A'S=	EVAP 3	COND	axial 994	WATTS/CH2
E R REY#	E A RET# 4208	LIQ REY#	C A REY#	C R REY#

HOT FLUID CHARGE 169-39 GRAMS
ROOM TEMP. VOLUME OF HOT FLUID CHARGE 12.5417 CM3

COLD FLUID CHARGE 173.995 GRAMS 12.8448 CM3

HEAT PIPE. (MESH) & 2 ENDCAPS 99.2507 GRANS

#### DELTA-T TALUES:

P. 10

130209	EVAP LoG •505764	EVAP MLSE •745609	EVAPORATION • 100093	DEG C
VAPOR (1) 1-39453	VAPOR (A) 1.37646	VAPOR (C) 109375		
CONDENSATION •244567 E-01	6272al•	00ND Lag •123971	COND WALL -3194332-01	Det c

POWER OF 350 WATTS CAUSES ----- CAPILLARY LIMIT, OPL > DPV

LAST MON-LIMITED POWER CALCULATION TAS AT ----- 385 WATTS

------ FOTAL DELFA-T = 5.d1 DEC C

RUM COMDITIONS	•			12129 P.H	1. 3/30/79
FLUID - MERCUR	T .	WALL MATE	50455		
EVAP TEMP - 2	77	TAPON DELT	L-T = 50	DEG C	
GRAY ANG - O	• 00	MES TIO =	0.CU D	W	00101111
					ORIGINAL PAGE IS
ADB LESS TH	13.9291	IX 43.00	DO CH		OF POOR QUALITY
ADS LESS TH	10.9291	II 63.00	אט טע		-
TOTAL LEGITE	103-1500	IN 505'00	DO CM		
O.D. VALL THEES	0.2500	IX 0.63	50 CM		
VALL THEMSS	0.0025	II 0.00	be ch		
GROOVE WIDTH GROOVE BEIGHT	0-1083	in 0.27	SO CK		
CHOIS BIDIS	0.1316	11 0.020	DO CH		
3 GROOVES (C)					
5 0x00125 (0.	<b>2002D</b> / <b>00</b>	1200 1118			
MO LIHIT EMCOU	ta difeth	********	26	4 VATTS	
	OTAL DELT		.35 DEB	C	
N					
MAKSOTEZY TEAV	CE DETAIL	S (Y OR E)	71		
PE	PE-A	34-	C	PC	DTHES/CH2
286642	240563	22	1004	224698	
13	TE-4	74	3	<b>2</b> C	DED C
275-719	TE-1 272.545	20	3.961	268.962	<b>32</b> (
		-			
EYAP TEMP 277	20B 646	P DEL	74-7 38382		
DFC= 127035	DPG= 0	DPC+DI	= 127035	DYN ES/CH2	
DPVE	DPL III	DP4.	<b>L</b>	DPLAG	
16048	4781		396	37334	
DP <b>v</b> C	DPLCG				
→	19636				
SORIC LINITS:	27	AP- 634	ADB-	630 VATTS	
Q/A* S=		COM	D		VATTS/CH2
	3	O		833	
E R PATA	S A REY# 3737		rky# 3	C A RET# 3801	C R RATO
HOT FLUID CHAR ROON TEMP. VOL		T FLUID CH		•187 GRANS 5636 CN3	
COLD FLUID CHA		995 GRANS 448 CN3			
HEAT PIPE, (ME	Seles e	NDCAPS 99	2607 GR	SKA	
DELTA-T VALUES:					
11 W 4 17 19 4 9 0	P+ n + -	*, <b>**</b> *	n wren	P# 4 fb 1 fb 4 fb 4 fb	
TYAP VALL	STAP LOG		ア 州之心は 7.7.4.7.4	-12000CE	n mar c
.111323	• Krightly	• 0	J. J. J	• 100080	JAN G
VAPOR (E)	VAPOR (A	1 7AP	OR (C)		
	3-58325		324225-03		

VAPOR (E) 3-17383	7APOR (A) 3.58325	7APOR (C) 7324225-03	3	
koltasation 10–3782 <del>44</del> 5.	•150789	008 7 Lug -106314	COMD WALL -2737512-01	D23 C
POWER OF	SERTAD RITAY 080	*******	CAPILLARY LIMIT.	DPL > DPV
LLST NOU-LIN	TIED POSET BALCE	LATION AAS AT		345 VATTS
	TOTAL DELTA-: = TOTAL AAST ==		G	

2 -

RUE COMDITIONS	1		12:46 P.H.	3/30/79
FLUID = MERCUR EVAP TIMP = 4 GHAV AMG = 0	T VA 34 VA 000 VT	LL HATL-30488 POR DELTA-T = 50 D ANG = 0.00 DE	DEC C	•
AVAP LENGTH ADB LENGTH COND LENGTH TOTAL LENGTH	33.8583 IN 0.0000 IN 69.2913 IN 103.1800 IN	3 ANG = 0.00 DH 30.0000 CM 0.0000 CM 176.0000 CM 202.0000 CM	Of to	YTHAUP 1
O-D- VALL PARMES GROOVE MIDTH GROOVE MEIGHT LAND WIDTH B GROOVES (C	0.2504 IE 0.0025 IX 0.1063 IX 0.0079 IK 0.0360 IE LOSEDI COVE	0.6360 CM 0.0064 CM 0.2750 CM 0.0200 CH 0.0915 CM RED VITE 200 HESE		,
		720 f = 2.50 DBG G		
VART PERFORMAN	OTAL MASS	- 0.290 EG		
PE •3896502+07	PE-A .388724 <b>3</b> +	PA-C 07 •3887213+07	PC •389094B+07	DTEES/CH2
TI - 432 <u>.</u> 39	18-A 432-216	7A-0 432.216	TC 432.265	DEG C
EVAP TEMP	COND TEMP	DELTA-7 2.50244		
DPC= 114073		DPC+DFG= 114073	DIN MS/CM2	
DPVE 9351 DPVC -3725	DPLEG 14532 DPLCG 29/42	DPVA O	DPLAG O	
SOUIC LIMITS:	ETAP	= 8646 ADB= 1	0334 VATTS	
0/A' S=	EVAP 4	CON D 2	arial 2266	YATTS/CM2
Z R REY#	7758	LIQ RET# 394	7759	C R REY#
HOT FLUID CHAR ROOM TEMP. FOL		FLUID CHARGE 15.2	234 Grans 247 Ch3	
COLD FLUID CEA		3 GRANS 4 CM3	,	
HEAT PILE, (ME	SII) & 2 END	CAPS 76.7047 GRA	NS	
DELTA-T VALUES				
27AP YALL •125096	671P 140 •598018	EVAP MESE •775944	EVAPORATION • 100098	DEG C
7470R (D) •174072	TAROR (A) •483881=-	74POR (C) 693359E-01		
condensation •469113E-01		00ND LLG •292541		DAG C
TOWER OF 165	ULS ETTLY 05	SZS 0	APILDALY DIAIT.	DPL > DPY
LAST MON-LINI	AD TOUTH CY	LCULATION FAS AT -	1	SZS VATTC

FLUID - MERCURT VALL MATL-30458 EVAP TEMP - 277 VAPOR DELTA-T - 50 DEG C GRAV ANG - 0.00 VTG ANG - 0.00 DEG

EVAP LERG TE 33.8683 IN 86.0000 CM
ADB LERG TE 0.0000 IN 0.0000 CM
COND LERG TE 69.2913 IN 176.0000 CM
TOTAL LERG TE 103.1600 IN 262.0000 CM

C.B.C.

0.D. 0.2500 IX 0.6350 CH
VALL TREES 0.0025 IS 0.0056 CM
GROOVE WIDTH 0.1083 IM 0.2750 CM
GROOVE BEIGHT 0.0079 IM 0.0200 CM
LAND WIDTH 0.1318 IN 0.3348 CM
3 GROOVES (CLOSED) COVERD WITH 200 MESS

HO LIMIT INCOUNTERED AT ------- 264 VATTS

TOTAL MASS = 0.275 EG

#### WART PERFORMANCE DETAILS (Y OR M) TY

PB 250631	<b>73-4</b> 240821	PA-0 240817	PG 240 <i>6</i> 17	DYE BS/CH2
7E 27 5.309	<b>73-4</b> 272-592	7A-C 272,502	TC 272-86	DEC C
EVAP TEMP 277	COND TEMP 272-21	DELTA-T 4-78955		
DPC= 126075	DPG= 0	DPC+DPG= 126975	DTN ES/CM2	
DPYE 19010 DPYC 199	DPLES 9559 DPLCG 19601	DPVA O	DPLAG O	

SOUIC LIMITS: EVAP- 641 ADB- 692 WATTS

Q/A'S= EVAP COND ARIAL WATTS/CH2
1 0 833

E R RET# E A RET# LIQ RET# C A RET# C R RET# 3731 206 3766 1

HOT FLUID CHARGE 170-18 GRAMS
RCON TEMP. VOLUTE OF BOT FLUID CHARGE 12-5631 CM3

COLD FLUID CHARGE 173.995 GRANS 12.8448 CNS

REAT PIPE. (MOSH) & 2 ELDCAPS 99.2507 GRANS

DELTA-T VALUES:

TOWER OF 500 (ACTS DANCED ----- ADB SOMIC LIMIT

LAS P MON-LIMITED FOR THE CALCULATION WAS AT ------ 495 WATTS

# AIRESEARCH MANUFACTURING COMPANY OF ARIZONA PHOENIX, ARIZONA

# APPENDIX B

HEAT PIPE COOLED NUCLEAR
REACTOR DESIGN INFORMATION
FROM
LOS ALAMOS SCIENTIFIC LABORATORY

(34 Pages)

31-3321 Appendix B

# HEAT-PIPE COOLED NUCLEAR REACTOR DESIGN INFORMATION FROM LOS ALAMOS SCIENTIFIC LABORATORY

This appendix contains the parametric information concerning heat-pipe-cooled reactor weights and sizes for use in the NASA Brayton power plant studies which was supplied by LASL. Data on gas cooled reactors was also furnished but not included herewith since such reactors received only very cursory attention in this study. The mass summary in Figure B-l indicates that 90%UC-10%ZrC fueled reactors are lighter but more limited in temperature than 60%UO<sub>2</sub>-40%Mo fueled reactors. Gas cooled reactors tend to be heavier below 1 MW<sub>t</sub> for 90%UC-10%ZrC and 4 MW<sub>t</sub> for 60%UO<sub>2</sub>-40%Mo.

For heat-pipe reactors, an allowance of 100°K was made for the temperature drop from the reactor heat pipes to the Brayton loop gas. This resulted in analyzing heat pipe reactors 100 degrees higher than the desired turbine inlet temperature. The turbine inlet temperatures AiResearch specified were 1150, 1325, 1500 and 1650°K. The accompanying tabulations provides information at various operating levels. It should be noted that the reactor mass includes one meter of heat pipes beyond the core for use in the heat exchanger but does not include the remainder of the heat exchanger. This mass can be adjusted as needed using the heat pipe mass/unit length values.

Both 90%UC-10%ZrC and 60%UO<sub>2</sub>-40%Mo fueled reactors with lifetimes of 10 years at full power were investigated. For the 90%UC-10%ZrC, excessive fuel swelling becomes a problem at 1425°K above 1 MW<sub>t</sub>. For lower temperatures and power levels, reactor sizes are limited by criticality and heat transfer considerations. For the region where excess swelling limitations govern, the power density in the fuel must be reduced. A number of means were examined including changing the void fraction in the fuel, reducing the <sup>235</sup>U enrichment, adjusting the heat pipe size and modifying the cladding matrix. Adjusting the void fraction will lead to the lowest weight core but at present it is only

an engineering estimate as to how much void can be accepted in a given design. It was concluded that the uncertainties and difficulties in design would not warrant designing a 90%UC-10%ZrC core if the power level and temperature exceeded 2 MW $_{\rm t}$  and 1425°K since the weight was approaching that of  $60\%UO_2$ -40%Mo at these conditions and would probably exceeded it by 4 MW $_{\rm t}$ .

The 60%UO-40%Mo reactor is criticality and heat transfer limited for the 1425, 1600, and 1750°K outlet temeprature cases except that above 2 MW<sub>t</sub> for 1750°K it becomes fuel-swelling limited. Based on our curent best information on fuel swelling, a 4 MW<sub>t</sub> reactor operating at 1750°K will have about 14 percent dense fuel swelling.

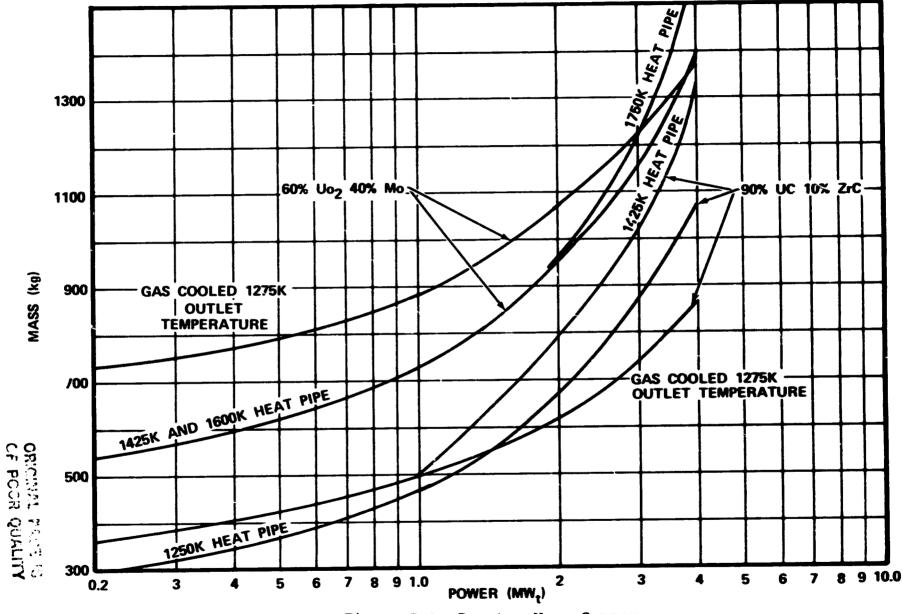


Figure B-1. Reactor Mass Summary.

STOP

PROF NO. 2 5-17-78 TIPE NEW INPUT: PERI. MAPRE ... STOP

```
(Mccama) (1,2/uc+uc2) come =uc
 0.200 (pm) proctom power-Hu
 1250. (THP) HEAT PIPE TEMPIDES K. (MASE) (1.2/55.550) PEPLECTOR PSEC
 3650, (TIME) LIPETINE DAYS
                                   (MMP) (1.2.3/NEIMOIN) HEAT PILE HMD
  1.00 (sup) come L/D MATEO
                                   (MUAPOR) (1,2/LI,NA) VAPOR
                                                                 BNA
  10.0 (DAVE) ASIAL HT PLUZEMUZCHE (TOPTN) (1-2)
                                                                 =2
                                                       OPTION
 200, (DYPHAY) HAY FUEL DELIA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE I 1-CODE PT DESIGN: 2-specified Design
  Type IN ANY OF FOLLOWING ! DCOPE(M) MPEF(M) MNFT FRETA NPIPE ..STOP
NPIPERRY STOP
             84
                 (HPIPE) NO. OF HEAT PIPES
              1014
                     VCD ALFA PKAVG BHIN DXMIN CORGAP ENDGAP
       PETA
      n.150 n.nos 0.050 0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: TTOP. OR NEW CONSTANTS IE. VC=0. PKANG=2, ETC ...STOP
υσ=0.012 εταρ
 FLD INDER T
uar = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 ror = 0.194 0.208 0.230 0.260 0.299 0.352 0.437 0.595 0.943 ◆.
 p_{CH} = 0. 0.192 0.135 0.110 0.095 0.085 0.078 0.072 0.067
• • • • • • • • • • • • • TYPE GO OR START DUER • • • • • • • • • • • •
60...84 PIPES
              \nu_{\rm MF} = 0.2743 \nu_{\rm F} = 0.7257
ESTA =0.1500
                                         - pm =0.1000 - pc =0.2237
 PERCTIVITY CHANGES: DELTA 12
     tuph = 0.00718 txp = 0.01512 tape = 0.02000 total = 0.04230
 FUEL ELEMENT VOLUME PRACTIONS
     CLADDING FUEL REGION HEAT PIPE
                                         WALLTWICK
                                                     VAROR
      0.0500
                 0.8642
                             0.0858
                                         0.0343
                                                     0.0515
 MEYARONAL CORNER CORRECTION FACTOR #1.0082
 NUMBER OF HEAT PIPES # 35.3550
   MINIMUM PRACTICAL (UR EPECIFIED) NUMBER OF HEAT PIPES *
 工艺的声音的两个心的话,因此他的两种个人的管理的意思。 化管止化工的
     MARIMUM FUEL DELTA T = 84.2
     AND DELTA T ACCROSS HEAT PIPE HALL # 4.7
     AUERAGE FUEL TEMPERATURE =1282.8
     MAKIMUM FUEL TEMPERATURE #1341.2
 BURN FRACTION OF 0235 \times 0.0120
 Fission bensity (Fissions/CM++3) = 2.498e+20
 FUEL EMELLINE WOLUME % = 0.92
 PERCTOR DIMENSIONS METERS
                                    FUEL ELEMENT DINENSIONS: MM
   0.2237 CORE DIAMETER
                                       23.11 WIDTH ACCROSS HEM PLATS
   0.2237
                                       24.26
          CERS HEIGHT
                                             EDUIV. FUEL ELEMENT DIA
   0.4537
                                       23.65
                                             EQUIV. FUEL PESION O.D.
          神智者に下口井 かまかい立て世界
   0.4337
                                        7.11
          网络西班牙四州 网络亚语科学
                                              HEAT PIPE D.D.
          REFLECTOR THICKNESS
   0.1000
                                        5.51
                                              VAROR DIAMETER
          PIPE LENGTH OUTSIDE PEACTOR
                                       23.80 VAPOR AREA: MM++2
   1.0000
   1.3287
           TOTAL HEAT PIPE LENGTH
   1.4337 DUERALL PEACTORTHEAT PIPE LENGTH
 PERCTOR METANTER KILDSPANS
             82.6 FUEL: UPRS MASS =
             148.7
                   PEFLECTO
             18.1 Heat pipes: UT/ONIT LENGTH (KG/M) = 13.60
             33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)
             19.8 suppost staucture (7% or meactor ut)
```

302.1 TOTAL REACTOR + HEAT PIRES

26.64 Mu/M\*\*3:AMS FOUR IN FUGLSPACE - 2.38 PULFOUER PER HEAT FIRE 100.03 MUMNY+2: HTRIPE AMIAL MT FLUX - 0.615 MUMY+2: HTRIPE PAD MTFLM

```
******
```

```
PROR NO. 3 5-17-78
                        TYPE NEW INPUT: PRE1. KMPE2 ...STOP
PRED. 4 STOP
                                  (kcame) (1.870c.oa2) came mud
0.400 (PP) PEACTOR POWER, NW |
1250. (THP) HEAT PIPE TEMP+DEG K (KREF) (1,2/8E-8ED) REFLECTOR #8ED
3650. (TIME) LIFETIME, DAYS (PHA) (1.2,3/NB, MO, W) HEAT PIPE AND
  1.00 (RLD) CORE L/D MATIO
                                  (KUAPOR) (1,2/LI,NA) VAPOR
  10.0 (paxe) axial at FLUX+KH/CM2 (idPin) (1+2)
                                                       DETION
                                                                #2
 200. (DTPMAY) MAY FUEL DELTA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-code PT DESIGN: 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING ! DCORE(M) MREF(M) MNFT FRETA NPIPE ..STOP
NPIPE#84 STOP
                  (NPIPE) NO. OF HEAT PIPES
                    VCD
                          みしぎ為
                                 PKANG SHIN
                                               DXMIN CORGAP ENDGAP
       BETA
              シに
      0.150 0.012 0.050
                          0.600 1.500 0.050 0.080 0.015 0.005
 TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
SLD INDEX =
\nu_{NF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 nc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
p_{GH} = 0. 0. 0.272 0.191 0.156 0.135 0.120 0.110 0.102 0.095
. . . . .
           * * * * * * TYPE GO DR START DUER * * * * * * * * * * * * * *
                           \nu_F = 0.6705 px = 0.1000 pc = 0.2381
BETA = 0.1500 UNF = 0.3295
REACTIVITY CHANGES, DELTA K
     supn = 0.01288 exp = 0.01512 expe = 0.02000 total = 0.04800
FUEL ELEMENT VOLUME FRACTIONS
    CLADDING
               FUEL PEGION
                             HEAT PIPE
                                         いみししせいまごと
                                                     VAROR
                0.7984
      0.0500
                             0.1516
                                        0.0606
                                                    0.0910
HEXAGONAL CORNER CORRECTION FACTOR =1.0258
NUMBER OF HEAT PIPES = 48.6978
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =
TEMPERATURE SUMMARY DEGREE KELVIN
     MAYIMUM FUEL DELTA T = 115.9
     ANG DELTA T ACCEDSS HEAT PIPE WALL F
                                            8.8
     AVERAGE FUEL TEMPERATURE =1297.5
     MAXIMUM FUEL TEMPERATURE =1379.2
BURN FRACTION OF 0235 \pm 0.0215
Fission density (Fissions/cm++3) = 4.474e+20
FUEL SMELLING, MOLUME % = 1.86
          " , desse fuel % = 2.19
REACTOR DIMENSIONS: METERS
                                    FUEL ELEMENT DIMENSIONS MM
                                       24.59 NIDTH ACCROSS HEY FLATS
  0.2381 COME DIAMETER
  0.2381 come Height
                                       25.82 EQUIV. FUEL ELEMENT DIA
  0.4681 PEACTOR DIAMETER
                                       25.17 EQUIP. FUEL REGION C.D.
  0.4481 веастор неізнт
                                       10.05 HEAT PIPE O.D.
  0.1000 PEFLECTOR THICKNESS
                                       7.79 VAPOR DIAMETER
  1.0000 PIPS LENGTH OUTSIDE REACTOR 47.64 VAPOR AREA: MM++2
  1.3431 TOTAL HEAT PIPE LENGTH
  1.4481 OVERALL PEACTOR+HEAT PIPE LENGTH
REACTOR WEIGHTS: KILDSPANS
             92.0 FUEL, U235 MASS = 78.2
            168.1 PEFLECTOR
             36.5 HEAT PIPES, WI/UNIT LENGTH (MG/M) = 27.21
             33.0 control system (assume constant = 33 \text{ kg})
             22.7 SUPPORT STRUCTURE (7% OF REACTOR WT)
            346.3 TOTAL REACTOR + HEAT PIPES
```

47.83 MU/M++3:AUG POUR IN FUELSPACE 4.76 KW:POUER PER HEAT PIPE 99.96 MU/M++2:HTPIPE AMIAL HT FLUM 0.817 MU/M++2:HTPIPE PAD HTFLM +++++++++++

```
-----
```

```
TYPE NEW INDUT: PRES. PAPES ... STOP
 PROP NO. 4
                      5-17-78
PR#0.7 STOP
                                                    (kcome) (1,2/uc+ud2) come ==uc
 0.700 (PP) PEACTOR POURF•NU
 1850. (THP) HEAT PIPE TEMP DEG K (KREE) (1:2/28:280) REFLECTOR PRED
                                                    (KHP) (1.2.3/NE, MO.W) HEAT PIPE MO
 3650. (TIME) LIFETIME, DAYS
                                                     (KUARDR) (1:2/LI:NA) VARDR
  1.00 (FLD) CORE L/D MATIO
                                                                                                   2112
   10.0 (paye) ARIAL HT FLUX-KW/CM2 (IDPTN) (1-2)
                                                                                    OPTION
                                                                                                   =2
   200. (DTEMAX) MAY FUEL DELTA TIDES K
   1.00 (HAL1) PIPE EXTENSION N
 NOTE: OPTIONS ARE: 1-CODE PT DESIGN. 2-SPECIFIED DESIGN
   TYPE IN ANY OF FOLLOWING : DCORE(M) MARF(M) WART FRETA NAIPE ..STOP
NPIPE=120 STOP
                   120
                           (NPIPE) NO. OF HEAT PIPES
                                        ALFA
                                                  PRADO BMIN
                      VC -
                               いても
                                                                         DWMIN CORGAP ENDGAP
            BETA
         0.150 0.012 0.050 0.600 1.500 0.050 0.080 0.015 0.005
   TYPP: STOP, OR NEW CONSTANTS IE. VC=0. PKAUGE2. ETC ...STOP
να≂9.008 εταρι
 SED INDEX #
 v_{\text{NF}} = 0.100 \, 0.200 \, 0.300 \, 0.400 \, 0.500 \, 0.600 \, 0.700 \, 0.800 \, 0.900 \, 1.000
   pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.535 0.943 ◆.
 p_{CH} = 0. 3.484 0.354 0.251 0.205 0.177 0.159 0.145 0.134 0.126
ullet 
30
 BETA = 0.1500 UNF = 0.3905 UF = 0.6095
                                                              px =0.1000
                                                                                 pc =0.2568
 PERCTIVITY CHANGES, DELTA K
        _{20PN} = 0.01977 exp = 0.01512 same = 0.02000 total = 0.05489
 FUEL ELEMENT VOLUME FRACTIONS
       CLADDING FUEL PEGION HEAT PIPE
                                                               MALLTHICK
                                                                                 レスを内容
                                                               0.0908
         0.0500
                          0.7229
                                            0.2271
                                                                                 0.1363
 HEXAGONAL CORNER CORRECTION FACTOR =1.0588
 NUMBER OF HEAT PIPES = 60.6776
    MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 120
 TEMPERATURE SUMMARY DEGREE KELLIN
        MAXIMUM FUEL DELTA T = 101.1
        AND DELTA T ACCROSS HEAT PIPE NAUL = 10.0
        AMERAGE FUEL TEMPERATURE =1293.7
        HAMINUM FUEL TEMPERATURE =1366.2
 BURN FRACTION OF 0235 \pm 0.0329
 Fishion density (Fissions/om+8) = 6.365e+20
 FUEL EMELLING MOLUME % = 8.77 , desc find % = 3.26
                                                       FUEL ELEMENT DIMENSIONES MM
 REACTOR DIMENSIONS, METERS
    0.2568 come planetem
                                                            22.24 WIDTH ACCROSS HEX FLATS
                                                            23.35
    0.2568 CORE HEIGHT
                                                                      EDUIN. FUEL ELEMENT DIA
    0.4868 PEACTOR DIAMETER
                                                            22.76 EQUIP. FUEL REGION O.D.
                                                            11.13 HEAT PIPE D.D.
    0.4668 REACTOR HEIGHT
    0.1000 PEFLECTOR THICKNESS
                                                            8.62 VAPOR DIAMETER
    1.0000 PIPE LENGTH DUTSIDE REACTOR 58.34 MAPOR AREA, MM++2
    1.3618 TOTAL HOAT PIPE LENGTH
    1.4AAA OMERALL REACTORTHEAT PIPE LENGTH
 REACTOR WEIGHTS: MILDSRAMS
                   104.9 FUEL: U235 MASS =
                                                             89.2
                   180.4 PEFLECTOR
                     64.8
                             HEAT PIPES, NT/UNIT LENGTH (MG/M) = 47.61
                     33.0 control system (Assume constant = 33 kg)
                    26.8 SUPPORT STRUCTURE (7% OF REACTOR UT)
                   409.9 TOTAL PEACTOR + HEAT PIPES
   73.39 MW/M++3.40G POWR IN FUELSPACE 5.83 PW.POWER PER HEAT PIRE
   99.98 MAKM++2.HTPIPE ARIAL HT FLUR - 0.839 MAKM++2.HTPIPE PAD HTPLX
```

\*\*\*\*\*\*

```
30
```

```
******
```

```
TYPE NEW INPUT: PRE! . KHP=2 ...STOP
              5-17-78
PR=1. STOP
                                   (kcoee) (1,2/uc,ud2) coee ==uc
 1.000 (PA) REACTOR POWER MA
 1950. (THE) HEAT PIPE TEMP, DEG H. (MREF) (1,2/PE, BED) PEFLECTOR FRED
                                    (KHP) (1.2.3/NB.MO.W) HEAT PIPE FMO.
3650. (TIME) LIFETIME DAYS
  1.00 (sup) come L/D MATIO
                                    (PUAROR) (1,2/LI,NA) MAROR -
  10.0 (days) AYIAS HT FEUX: FUZCHE (IDPTN) (1:2)
                                                                    ≖2
                                                         DETIDM
 200. (DTFMAX) MAX FUEL DELTA TYDES K
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DOORE(M) MARKEN) WHAT FRETA NAIRE .. STOP
NPIPE=162 STOP
             162
                 (NPIPE) NO. OF HEAT PIPES
        BETA
              175
                      VCD
                            ALFA
                                  严权两尺位 原門工科
                                                 DXMIN CORGAP ENDGAP
      0.150 0.008 0.050 0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PMANGEZ. ETC ...STOP
\nuc=0.006 stop
 SUD INDEX #

u_{\rm MF} = 0.100 \, 0.200 \, 0.300 \, 0.400 \, 0.500 \, 0.600 \, 0.700 \, 0.800 \, 0.900 \, 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
DCH = 0. 2.606 0.419 0.298 0.244 0.212 0.189 0.173 0.160 0.150
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆

u_{\rm F} = 0.5617

                                          p \times = 0.1000
BETA = 0.1500 UNF = 0.4383
                                                       pc ≃0.2737
REACTIVITY CHANGES, DELTA M
      puen = 0.02533 exp = 0.01512 safe = 0.02000 total = 0.06045
FUEL ELEMENT MOLUME FRACTIONS
                                           MALL+MICK
                                                       Neede
                FUEL REGION HEAT PIPE
     CLADDING
                                                       0.1711
      0.0500
                  0.6648
                              0.2852
                                           0.1141
 HEXAGONAL CORNER CORRECTION FACTOR =1.0943
Number of Heat Pipes \approx 68.6911
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 162
 TEMPERATURE SUMMARY, DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 84.8
      ANG DELTA T ACCROSS HEAT PIPE HALL = 9.9
      AMERAGE FUEL TEMPERATURE =1288.2
      MAXIMUM FUEL TEMPERATURE =1349.7
 8080 FRACTION OF 0835 = 0.0488
 Fission Density (Fissions/cm++3) = 8.796e+20
 FUFL SWELLING POLUME % = 3.39
      ", dense fact % = 3.99
 PEACTOR DIMENSIONS, METERS
                                      FUEL ELEMENT DIMENSIONS. MM
  0.2737 come bramerem
                                         20.42 WINTH ACCROSS HEW FLATS
  0.2737 CORE HEIGHT
0.5037 REACTOR DIAMETER
0.4837 REACTOR HEIGHT
                                         21.44 EQUIV. FUEL ELEMENT DIA
                                         20.89
                                               EDUIV. FUEL PEGION 0.5.
                                        V11.45
                                               HEAT PIPE D.D.
   0.1000 PERLECTOR THICKNESS

√8.87

                                                MARCR DIAMETER
   1.0000 PIPE LENSTH OUTSIDE REACTOR 61.75 MAPOR AREA: MM++8
< 1.3787
          TOTAL HEAT PIPE LENGTH
  1.4837 OVERALL REACTOR+HEAT PIPE LENGTH
REACTOR NEIGHTS: MILDERAMS
             117.0 FUEL: U235 MASS =
                                          99.4
             197.8 REFLECTOR
              93.8 HEAT PIPES: UT/UNIT LENSTH (KG/M) = 68.02
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)
              30.9 suppose staucture (7% of REACTOR AT)
             472.5 TOTAL REACTOR + HEAT PIPES
                                        6.17 KUPDHER PER HEAT PIPE
 94.08 MU/M++3+AMS POUR IN FUELSPACE
```

99.97 MM/M++2+HTPIPE AKIAL HT FLUK - 0.810 MM/M+2+HTPIPE PAD HTFLX

```
*****
```

```
PROP NO. 6 5-17-78
                         TYPE NEW INPUT: PRE! KHPES ...STOP
PR#2. STOP
                                  (kcome) (1,2/uc,ud2) come =uc
2.000 (PP) PEACTOR POWER MN
 1250. (THP) HEAT PIPE TEMP+DEG K (KREE) (1.2/BE:BEG) REPLECTOR FRED
                                   (KHP) (1:2:3/NB:MO:N) HEAT PIPE #MO
 3650. (TIME) LIFETIME DAYS
  1.00 (SUD) COME L/D MATIO
                                   (KUAPOR) (1,2/LI,NA) VAPOR -
                                                                 =2
  10.0 (daxe) Axiae at Feux, Mazch2 (10PTA) (1,2)
                                                       DETION
  200. (DIFNAY) MAY FUEL DELTA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) MREF(M) MNFT FRETA NPIPE ..STOP
NPTPE=210 STOP
            210 (NPIPE) NO. OF HEAT PIPES
             NC
                     NCD
                          ALFA
                                 かくめいき まりまり
                                                DXMIN COPGAP ENDGAP
       RETA
      n.150 0.006 0.050 0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
vc=.005 stop
SED INDEX =
\nu_{HF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
            3.228 0.590 0.421 0.345 0.299 0.268 0.244 0.226 0.212
 pch = 0.
          ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆
3Q
               MNE =0.5467
                             νρ =0.4533 οκ =0.1000 ος =0.3210
BETA ≈0.1500
REACTIVITY CHANGES! DELTA K
     p_{\text{UPN}} = 0.03890 \text{ gap} = 0.01512 \text{ gaps} = 0.02000 \text{ TOTAL} = 0.07402
FUEL ELEMENT MOLUME FRACTIONS
    CLADDING
               FUEL PEGION HEAT PIPE
                                         MALLTHICK
                                                     0.2484
      0.0500
                0.5360
                              0.4140
                                          0.1656
HEYAGONAL CORNER CORRECTION FACTOR =1.2092
 NUMBER OF HEAT PIPES = 84.9168
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES # 210
 TEMPERATURE SUMMARY, DEGREE KELVIN
     MAXIMUM FUEL DELTA T = 80.9
      ANG DELTA T ACCROSS HEAT PIPE HALL = 13.1
      AVERAGE FUEL TEMPERATURE =1290.0
     HAMIMUM FUFL TEMPERATURE =1350.5
 guen spaction of 0235 \pm 0.0648
 Fission Density (Fissions/cm++3) = 1.351E+21
 FUEL EMELLING, VOLUME % = 5.29
          " dense fuel 7 : 6,22
                                     FUEL ELEMENT DIMENSIONS, MM
 REACTOR DIMENSIONS, METERS
                                        21.04 WIDTH ACCROSS HEX FLATS
   0.3810 COME DIAMETER
                                       22.09
                                              EQUIV. FUEL ELEMENT DIA
   0.3210 COME HEIGHT
                                       21.54 EQUIV. FUEL REGION O.D.
   0.5510 PEACTOR DIAMETER
                                       14.22 HEAT PIPE O.D.
   0.5310 REACTOR HEIGHT
   0.1000 PERCECTOR THICKNESS
                                        11.01 VAPOR DIAMETER
   1,0000 PIPS LENGTH OUTSIDE PEACTOR 95.24 MAPOR AREA: MM++2
   1.4860 TOTAL HEAT PIPE LENGTH
   1.5310 DMERALL REACTOR HEAT PIPE LENGTH
PEACTOR MEIGHTS: KILOGRAMS
             158.4 FUEL, 0235 MASS = 129.5
             251.5 REFLECTOR
             193.9 Heat Pipes, MT/UNIT LENGTH (KG/M) = 136.00
              33.0 CONTROL SYSTEM (ASSUME CONSTANT # 33 Kg)
              44.2 SUPPORT STRUCTURE (7% OF REACTOR NT)
             674.9 TOTAL REACTOR + HEAT PIPES
```

```
*************
```

```
PROP NO. 7
               5-17-78
                            TYPE NEW INPUT: PRE! ... STOP
PRE4. ETOP
 4.000 (PP) PEACTOR POWERSHU
                                     (MCORE) (1:2/UC:UG2) cope = #UC
 1250. (THP) HEAT PIPE TEMPIDES H (KREE) (1:2/se;sed) REFLECTOR MEED
 3650. (TIME) LIFETIME DAYS
                                    (KHP) (1.2.3/NB.MO.W) HEAT PIPE =MO
  1.00 (sun) come u/p mario
                                      (KUAPOR) (1:2/LI:NA) DAPOR
                                                                      #11A
  10.0 (daxe) axial at flux. Muzca2 (ideta) (1.2)
                                                            DETIDN
                                                                       #2
  200. (DIFMAX) MAX FUEL DELTA TIDES K
  1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING : DODRE(M) MAREF(M) WHET FRETA HAIRE .. STOP
NPIPER264 STOP
                  (NPIPE) NO. OF HEAT PIPES
             264
              ルビ
                      VCD ALFA PKAVG BMIN
        BETA
                                                    DXMIN COMGAP ENDGAP
 0.150 0.005 0.050 0.600 1.500 0.050 0.080 0.015 0.005
Type: Stop. Of New Constants 16. VC=0. PMAVG=2. etc ...Stop
νσ≈0.004 sτοε
 SLD INDEX =
m_{F} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
 рсн = 0. 4.111 0.832 0.594 0.487 0.422 0.378 0.346 0.320 0.300
* * * * * * * * * * * * * TYPE GO OR START OMER * * * * * * * * * * * *
rich.
BETA = 0.1500 \nuNF = 0.6570
                              ν⊨ ≖0.3430
                                            p \times = 0.1000
                                                           pc = 0.3954
PERCTIVITY CHANGES, DELTA K
      {\tt BUPN} = 0.05500 {\tt EXP} = 0.01512 {\tt SAFE} = 0.02000 {\tt TOTAL} = 0.09012
 FUEL ELEMENT MOLUME FRACTIONS
     CLADITME
                FUEL PEGION
                              HEAT PIPE
                                             NALL+NICK
                                                         MARCR
      0.0500
                   0.4051
                                0.5449
                                             0.2180
                                                         0.3269
MEYAGONAL CORNER CORRECTION FACTOR =1.3895
NUMBER OF HEAT PIPES = 101.8710
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 264
TEMPERATURE SUMMARY DEGREE MELVIN
     HAMINUM FUEL BELTA T = 77.2
      AMB DELTA T ACCADES HEAT PIPE WALL = 16.9
      AMERAGE FUEL TEMPERATURE =1292.6
      MAXIMUM FUEL TEMPERATURE =1352.5
 BURN FRACTION OF 0235 = 0.0917
Fission density (Fissions/ch++3) = 1.910e+21
FUEL SWELLING, VOLUME % = 7.64
         " , dease fuel % = 8,99
PEACTOR DIMENSIONS: METERS
                                       FUEL ELEMENT DIMENSIONS, HM
   0.3954 COPE DIAMETER
                                          23.13 WIDTH ACCROSS HEX FLATS
  0.3954 CORE DIRECTER
0.3954 CORE HEIGHT
0.6254 REACTOR DIRECTER
0.6054 REACTOR HEIGHT
0.1000 REFLECTOR THICKNESS
                                          24.29
                                                 EDUIY. FUEL ELEMENT DIA
                                          23.67 EQUIV. FUEL REGION O.D.
                                          17.93 HEAT PIPE 0.D.
                                          13.89 VAPOR DIAMETER
   1.0000 PIPE LENGTH DUTSIDE REACTOR 151.46 VAPOR AREA: MM++2
   1.5004 TOTAL HEAT PIPE LENGTH
  1.6054 OMERALL REACTOR HEAT PIPE LENGTH
PEACTOR NEIGHTS: MILDSPANS
             215.5 FUEL: 0235 MASS = 183.2
             350.0 PEFLECTOR
             408.0 HEAT PIPES, UT/UNIT LENGTH (KG/H) = 271.50
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 \text{ kg})
              70.5 SUPPORT STRUCTURE (7% OF REACTOR NT)
            1076.9 TOTAL PEACTOR + HEAT PIPES
```

204.17 HU/M\*\*3:AUG POUR IN FUELSFACE | 15.15 KU:POUER PER HEAT PIRE 100.04 MU/M++2.HTFIPE AMIAL HT FLUM 0.878 MU/M++2.HTFIPE RAD HTFLM \*\*\*\*\*\*\*\*\*\*\*\*

```
*************
                          TYPE NEW INPUT: PREI, KHARE ... STOP
PROP NO. 8 5-17-78
PP=0.2 THP=1425. STOP
                                   <kcome> <1+2/uc+uo2> come =uc
 0.200 (ee) egactoe equeethu
 1425, (THE) HEAT PIPE TEMP, DEG K. (KREE) (1,2/be, beg) PEPLECTOR HEED
      TIME LIFETIME DAYS
 3650.
                                    (KHP) (1:2:3/NE:MO:N) HEAT PIPE HAD
                                    (KUAPOR) (1:8/LI:NA) VAPOR
 1.00 (sup) come L/D MATIO
 10.0 (past) Asiat HT FLUM: KH/CH2 (IDPTN) (1:2)
                                                         OPTION
                                                                   =2
 200. (birnay) Hay FUEL DELTA TYDES H
 1.00 (HPL1) PIPE EXTENSIONSH
NOTE, OPTIONS ARE: 1-CODE PT DESIGN. 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING : DCORE(M) MARROWN) MART FRETA MAIRE .. $TOP
NPIPE=34 STOP
              34
                 (NPIPE) NO. OF HEAT PIPES
                     VCD
                           ALPA PKAVG BMIN
                                                 DYMIN CORGAP ENDGAP
      0.150 0.004 0.050 0.600 1.500 0.050 0.080 0.015 0.005
 TYPE: STOP: OF NEW CONSTANTS IE, VC=0, PKAVG=2, ETC ...STOP
VC=.012 STOP
SLD INDEX =
v_{BF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
p_{CH} = 0. 0. 0.192 0.135 0.110 0.095 0.085 0.078 0.072 0.067
* * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * *
60
BETA = 0.1500 PNF = 0.2743
                              VF ≠0.7257 px ≠0.1000 pc ≠0.2237
REACTIVITY CHANGES, DELTA K
      EURN = 0.00718 \text{ exp} = 0.01764 \text{ safe} = 0.02000 \text{ total} = 0.04482
FUEL ELEMENT VOLUME FRACTIONS
     CLADDING
              FUEL PEGION
                            HEAT PIPE
                                           HALLTHICK
                                                       ジシャロネ
      0.0500
                  0.8642
                              0.0858
                                          0.0343
                                                       0.0515
HEXAGONAL CORNER CORRECTION FACTOR =1.0082
NUMBER OF HEAT PIPES = 35.3550
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 84
TEMPERATURE SUMMARY DEGREE MELVIN
     MAKIMUM FUEL DELTA T = 84.2
     AMB DELTA T ACCROSS HEAT PIPE MALL # 4.7
      AVERAGE FUEL TEMPERATURE =1457.8
     HAMINUM FUEL TEMPERATURE #1516.2
Even FRACTION OF 0235 \pm 0.0120
Figgion Density (Fissions/cn++3) = 2.492e+20
FUEL SHELLING*HOLUME % = 3.27
      " , dense fuel 9 = 3.85
REACTOR DIMENSIONS: METERS
                                     FUEL ELEMENT DIMENSIONS: HM
  0.2237 come planetem
                                         23.11 WIDTH ACCROSS HEX FLATS
  0.2237
  0.2237 CORE HEIGHT 0.4537 REPOTOR DIAMETER
                                         24.26
                                               EDUIV. FUEL ELEMENT DIA
                                        23.65 EQUIV. PUEL REGION 0.0.
  0.4337
         PEACTOR HEIGHT
                                         7.11 HEAT PIPE D.D.
  0.1000 REFLECTOR THICKNESS
                                         5.51 VAPOR DIAMETER
  1.0000 PIPE LENGTH OUTSIDE REACTOR 23.80 VAPOR AREA, MM++2
  1.3287
          TOTAL HEAT PIPE LENGTH
  1.4337 OMERACE REACTOR HEAT PIPE LENGTH
REACTOR NEIGHTS: KILOGRAMS
             82.6 FUEL, U235 MASS #
                                          70.2
             148.7 PEFLECTOR
             18.1 HEAT PIPES UT/UNIT LENGTH (MG/M) = 13.60
             33.0 control system (assume constant = 33 \text{ kg}) 19.8 support structure (7% of peactor wt)
```

302.1 TOTAL PEACTOR + HEAT PIPES

26.64 MU/M++3-ANG POWR IN FUELSPACE 2.38 MU-POWER PER HEAT PIRE  $100.03~{\rm MU/M++2-HTPIPE}$  RAD HTFLX

```
•••••
```

```
PROP NO. 9 5-17-78
                           TYPE NEW INPUT: PRE1. KHPE2 ... STOP
P##0.4 KTOP
 0.400 (PP) PEACTOR POWERSHU
                                   (Koope) (1,2/Uc,Uo2) cope =uc
 1425. (THE) HEAT PIPE TEMP*DEG K (KREE) (1:2/8E:1EO) PEPLECTOR #9EO 3650. (TIME) LIPETIME:DAYS (KMP) (1:2:3/NB:(IO:N) HEAT PIPE #MO
 3650. (TIME) LIFETIME, DAYS
1.00 (SLD) COME L/D MATIC
                                    (KNAPOP) (1:2/LI:NA) VAPOP = HA
 10.0 (DAML) AMIAL HT FLUM: MH/CH2 (IDFTH) (1:2)
                                                          OPTION
                                                                    =2
  200. (DIFMAX) MAX FUEL DELTA TIDES K
 1.00 (MPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1--CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DOORE(H) MREF(H) WHET FEETA MPIPE ..STOP
NPIPE=84 STOP
              24
                   (NPIPE) NO. OF HEAT PIPES
                      いての 再し作品
                                   PRAVE BHIN DENIN CORSAP ENDSAP
      0.150 0.012 0.050 0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 v_{\rm MF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
 p_{CH} = 0, n_{c} = 0.272 \ 0.191 \ 0.156 \ 0.135 \ 0.120 \ 0.110 \ 0.102 \ 0.095
* * * * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * * * *
 BETA =0.1500 UNF =0.3295
                             □ νε =0.6705 | p× =0.1000 | pc =0.2381
 REACTIVITY CHANGES: DELTA K
      y_{MAN} = 0.01288 \text{ gMp} = 0.01764 \text{ same} = 0.02000 \text{ total} = 0.05052
 FUEL ELEMENT VOLUME FRACTIONS
              FUEL PEGION HEAT PIPE
                                            NACETHICK
     CLADDING
                                                        VAPOR
                  0.7984
      0.0500
                               0.1516
                                           0.0606
                                                         0.0910
 HEMAGONAL CORNER CORRECTION FACTOR #1.0258
 Number of Heat Pipes = 48.6978
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES # 84
 TEMPERATURE SUMMARY DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 115.9
      AND DELTA T ACCROSS HEAT PIPE NAUL = 8.8
      AMERAGE FUEL TEMPERATURE =1472.5
      MARINUM FUEL TEMPERATURE =1554.2
 BURN FRACTION OF 0235 \pm 0.0215
 Fission density (Fissions/CH++3) = 4.474e+20
 FUEL SUBLLING WOLUME % = 6.44
               , dense fuel 4. = 7,58
      11
 REACTOR DIMENSIONS, METERS
                                      FUEL ELEMENT DIMENSIONS, MM
   0.2381 COME DIAMETER
                                          24.59 WIDTH ACCROSS HEX FLATS
   0.2381 come Hetcht
                                          25.82 EQUIV. FUEL ELEMENT DIA
                                          25.17 EQUIV. FUEL REGION O.D. 10.05 HEAT PIPE O.D.
   0.4681 REACTOR DIAMETER
   0.4481 REACTOR HEIGHT
                                          7.79 VAPOR DIAMETER
   0.1000 PEFLECTOR THICKNESS
   1.0000 PIPE LENGTH DUTSIDE PEACTOR 47.64 VAPOR AREA, MM++2
   1.3431 TOTAL HEAT PIPE LENGTH
   1.4481 OMERALL REACTORTHEAT PIPE LENGTH
 PEACTOR MEIGHTE: KILDSPAMS
              92.0 FUEL, 0235 MASS = 78.2
             162.1 MEFLECTOR
              36.5 HEAT PIPES, UT/UNIT LENGTH (\kappa s/n) = 27.21
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)
              22.7 SUPPORT STRUCTURE (7% OF REACTOR NT)
             346.3 TOTAL PEACTOR + HEAT HIPES
  47.83 MUZH++3×AUG POUP IN FUELSPACE 4.76 KM×POUEP PER HEAT PIPE
```

99.96 MUZM++2.HTPIPE AMIAL HT FLOM 0.817 MUZM++2.HTPIPE PAD HTFLM

TYPE GO OR STOP

### \*\*\*\*\*\*

```
TYPE NEW INPUT: PREI. KMP=2 ... TOP
               5-17-78
PROR NO. 10
ee=0.7 stoe
                                   (Koppe) (1,2/Uc,Up2) cope = #Uc
 0.700 (em) practom rouge inc
 1425. (THP) HEAT PIPE TENPIDES V=(\mathsf{KPEP})/(\mathsf{1},\mathsf{2}/\mathsf{3e},\mathsf{3e}) PEFLECTOR F380.
 3630. (TIME) LIFETIME DAYS
                                   (KHP)(1,2,3/NE,MO,W) HEAT PIPE FMO
                                    (KUAPOR) (1,2/LI,NA) VAPOR
                                                                    -
 1.00 (gup) come L/D MATIO
 10.0 (desc) ested at FLUS-KNZCH2 (toPTN) (1-2)
                                                                    =2
                                                         OPTION
 200. (STENAY) MAY FUEL DELTA TYDEG K
 1.00 (HPL1) PIPS EXTENSIONED
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-specified Design
 TYPE IN ANY OF FOLLOWING : DCORE(M) MREF(M) UNFT FRETA NPIPE ..STOP
NPIPE=120 STOP
             120 (NPIPE) NO. OF HEAT PIPES
                     VCD
                           ALFA
                                  PKAUG BMIN
                                                 DYMIN COMMAP ENDMAP
        RETA
              レニ
      0.150 0.012 0.050 0.600 1.500 0.050 0.080 0.015 0.005
 TYPE: STOPE OR NEW CONSTANTS IS. VC=0. PKAVG=2. STC ...STOP
vc=0.008 stc#
SLD INDEX =
vos = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
p_{GH} = 0. 3.484 0.354 0.251 0.205 0.177 0.159 0.145 0.134 0.126
          ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
30
BETA =0..500 \nu_{\rm MF} =0.3905 \nu_{\rm F} =0.6095 \tau_{\rm M} =0.1000 \tau_{\rm C} =0.2568
REACTIVITY CHANGES: DELTA K
      euph = 0.01977 exp = 0.01764 exp = 0.02000 exp = 0.05741
FUEL ELEMENT MOLUNE FRACTIONS
     CLADDING FUEL REGION HEAT PIPE MALLTHICK
      0.0500
                 0.7229
                             0.2271
                                           0.0908
                                                       0.1363
HEYAGONAL CORNER CORRECTION FACTOR =1.0588
Number of Heat Pipes = 60.6776
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES # 120
TEMPERATURE SUMMARY, DEGREE MELVIN
      MAXIMUM FUEL DELTA T = 101.1
      AND DELTA T ACCROSS HEAT PIPE HALL = 10.0
      AMERAGE FUEL TEMPERATURE =1468.7
      HAMINUM FUEL TEMPERATURE =1541.2
BURN FRACTION OF 0235 =0.0329
rtssion bensity (rissions/ch+43) = 6.865e+20
FUEL SMELLING-VOLUME \% = 9.65
               dense fuel 4. = 11.35
REACTOR DIMENSIONS, METERS
                                      FUEL ELEMENT DIMENSIONS: NH
                                         22.24 WIDTH ACCROSS HEX FLATS
   0.2568 CORE DIAMETER
   0.2568 COME HEIGHT
                                         23.35 EQUIV. FUEL ELEMENT DIA
   0.4868 PEACTOR DIAMETER
                                         22.76 EQUIV. FUEL REGION D.D.
   0.4668 REACTOR HEIGHT
                                         11.13 HEAT PIPE D.D.
  0.1000 PEFLECTOR THICKNESS
                                         8.62 VAPOR DIAMETER
  1.0000 Pips Length dutsibe peactor 58.34 Vapop apea, MM++2
  1.3618 TOTAL HEAT PIPE LENGTH
  1.4668 OVERALL REACTORPHEAT PIPE LENGTH
REACTOR NEIGHTS: KILOGRAMS
             104.9 FUEL: 0235 MASS = 89.2
             180.4 REFLECTOR
              64.8 HEAT PIPES: NT/UNIT LENGTH (MG/H) = 47.61 33.0 CONTPOL SYSTEM (ASSUME CONSTANT = 33 MG)
              26.8 SUPPORT STRUCTURE (7% OF REACTOR UT)
             409.9 TOTAL PEACTOR + HEAT PIPES
                                        5.83 KN-PONER PER HEAT PIPE
 73.39 mu/n++3+aug pour in fuelspace
```

99.98 mu/n++2.Htripe Asial Ht Flus - 0.839 mu/n++2.Htripe pap Htrlx

TYPE NEW INPUT: PR=1. KHP=2 ...STOP

```
Avecage) (1:2/uc:ua2) came suc
1.000 (PP) REACTOR POWER NW
 1425, (THP) HEAT PIPE TEMP+DEG K (KREP) (1+2/BE+SEG) REPLECTOR REED
3650. (TIME) LIFETIME, DAYS
                                   (KHP) (1:2:3/NE:MO:H) HEAT PIPE #MO
                                   (MUAPOR) (1:2/LI:NA) VARDRI
  1.00 (ELD) COME L/D MATTO
                                                                   SNA
  10.0 (pake) Aktae HT FEUKIRHZCM2 (IDPTN) (1:2)
                                                                   =2
                                                        DETIDA
 200. (DTPMAY) MAX FUEL DELTA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M) MARF(M) MART FRETA NPIPE .. STOP
NPIPE=162 STOP
             162
                 (NPIPE) NO. OF HEAT PIPES
                      VCD
                                  PKAVG BMIN
        BETA
              175
                            ALFA
                                                DXMIN CORGAP ENDGAP
                           0.600 1.500 0.050 0.080 0.015 0.005
      0.200 0.006 0.050
 TYPE: TIDE, OR NEW CONSTANTS IE. VC=0. PMAVG=2. ETC ...STOP
BETA=0.25 STOP
BLD INDEX =
v_{NF} = 0.100 \, 0.200 \, 0.300 \, 0.400 \, 0.500 \, 0.600 \, 0.700 \, 0.800 \, 0.900 \, 1.000
  p_C = 0.196 \ 0.203 \ 0.230 \ 0.260 \ 0.299 \ 0.352 \ 0.437 \ 0.585 \ 0.943 \bullet.
                1.391 0.383 0.276 0.227 0.197 0.177 0.162 0.150
DCH = Q.
           o.
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO DR START DUER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
GO...ADJUST BETA FOR 10% SHELLING
                                         p \times = 0.1000 p \in = 0.2904
SETA = 0.2500 UNF = 0.4804 UF = 0.5196
REACTIVITY CHANGES: DELTA K
     _{\rm SUBN} = 0.02290 exp = 0.01764 gape = 0.02000 total = 0.06054
FUEL ELEMENT VOLUME FRACTIONS
                                          NACCHMICK
     CLADDING FUEL PEGION
                              HEAT FIFE
                                                       UAPOR
                  0.6970
                              0.2530
      0.0500
                                          0.1012
                                                       0.1518
HERAGONAL CORNER CORRECTION FACTOR #1.0735
NUMPER OF HEAT PIPES # 70.8802
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 162
LENNERSHILLING BUNNWALL DEGMEE KEININ
     MAXIMUM FUEL DELTA T = 87.5
     ANG DELTA T ACCEDSS HEAT PIPE HALL A
     AVERAGE FUEL TEMPERATURE =1463.5
     MAKIMUM FUEL TEMPERATURE =1526.6
PURN FRACTION OF 0235 \pm 0.0382
FISSION DENSITY (FISSIONS/CM++3) = 7.017e+20
FUEL SHELLING NOLUME % = 9.54
PERCTOR DIMENSIONS: METERS
                                     FUEL ELEMENT DIMENSIONS: MM
                                        21.67 WIDTH ACCROSS HEX FLATS
  0.2904 COME DIAMETER
          CORE HEIGHT
  0.2904
                                        22.75
                                               EDUIV. FUEL ELEMENT DIA
  0.5204 PEACTOR DIAMETER
                                        22.18 EQUIV. FUEL PEGION D.D.
  0.5004 PEACTOR HEIGHT
                                        11.44 HEAT PIPE D.D.
   0.1000 PEFLECTOP THICKNESS
                                         8.86 VAPOR DIAMETER
  1.0000 PIPE LENGTH OUTSIDE PERCTOR 61.71 MAPOR AREA, MM++2
  1.3954 TOTAL HEAT PIPE LENGTH
  1.5004 DMEPALL PEACTOR HEAT PIPE LENGTH
PEACTOR MEIGHTS: KILOGRAMS
             129.4 FUEL: 0235 MASS = 110.0
             216.1 PEFLECTOR
              94.9 HEAT PIPES, WIZUNIT LENGTH (KGZM) = 67.98
              33.0 contpol system (assume constant = 33 kg)
              33.1 SUPPORT STRUCTURE (7% OF REACTOR WT)
             506.4 TOTAL PEACTOR + HEAT PIPES
```

75.01 MNZM++3+AMS POWE IN FUELSPACE 6.17 MN+POWER PER HEAT PIPE 100.03 MNZM++2+HTPIPE AXIAL HT FLUX 0.763 MNZM++2+HTPIPE PAD HTPLX

\*\*\*\*\*\*\*\*

```
PROP NO. 16 5-17-78
                       TYPE NEW INPUT: PRE! KMP=2 ... STOP
FTOP
```

```
2.000 (FR) REACTOR PONERS NO
                                  (McDee) (1:2/Uc:Ud2) coes = #Uc
 1425, (THP) HEAT PIPE TEMP, DEG K. (PREP) (1.2788)880) PEPLECTOR =880
 3650. (TIME) LIPETIME DAYS -
                                  (KHP)(1:2:3/NB:MO:W) HEAT PIPE HMG
 1.00 (SLD) CORE L/D MATTO
                                   (KUAPOR) (1:2/LI:NA) VAPOR -
                                                                  BHA
 10.0 (dake) aktae ht feukikh/cm2 (toptn) (1:2)
                                                        OFTION
                                                                  ≈≥
 200. (DTFMAX) MAX FUEL DELTA TIDES K
  1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING ! DCORE(M) XREF(M) WNFT FRETA NPIPE ..STOP
NPIPE#210 STOP
             210 (NPIPE) NO. OF HEAT PIPES
                           ALFA
                                  PKANG BMIN
                                               DXMIN CURGAP ENDSAP
        BETA
              NE
                     いこわ
      0.500 0.005 0.050 0.600 1.500 0.050 0.080 0.015
  TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
BETARO.4 STOP
 FLD INDEX #
\nu_{\rm MF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
 p_{CH} = 0, 0. 0. 0. 0.616 0.390 0.309 0.263 0.233 0.212
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OM STAMT GVEM ◆ ◆ ◆ ◆ ◆
GO...ADJUST BETA FOR 10% SWELLING
ESTA = 0.4000 VNF = 0.6217 VF = 0.3783 px = 0.1000 pc = 0.3672
REACTIVITY CHANGES, DELTA K.
     _{\text{BURN}} = 0.03113 _{\text{EXP}} = 0.01764 _{\text{SAFE}} = 0.02000 _{\text{TOTAL}} = 0.06877
FUEL ELEMENT VOLUME FRACTIONS
               FUEL PEGION HEAT PIPE
                                          HALLTHICK
                                                      VAPOR
    こしきもりませる
      0.0500
                0.6336
                             0.3164
                                          0.1265
                                                      0.1898
HENAGONAL CORNER CORRECTION FACTOR #1.1173
NUMBER OF HEAT PIPES = 94.2127
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIRES = 210
 TEMPERATURE SUMMARY, DEGREE PELVIN
     MAKIMUM FUEL DELTA T = 89.7
     ANG DELTA T ACCEDES HEAT FIRE WALL # 11.4
     AMERAGE FUEL TEMPERATURE =1466.3
     MARIMUM FUEL TEMPERATURE #1531.9
 BURN FRACTION OF 0235 #0.0519
FISSION DENSITY (FISSIONS/CM++3) = 7.630e+20
FUEL EMELLING MOLUME % =10.56
 REACTOR DIMENSIONS, METERS
                                     FUEL ELEMENT DIMENSIONS: MM
  0.3672 COME DIAMETER
                                        24.07 WIDTH ACCROSS HEX FLATS
   0.3672 came Height
                                        25.28 EQUIP. FUEL ELEMENT DIA
   0.5972 REACTOR DIAMETER
                                        24.64 EQUIV. FUEL PEGION O.D.
   0.5772 PEACTOR HEIGHT
                                        14.22 HEAT PIPE O.D.
  0.1000 PRELECTOR THICKNESS
                                        11.01 VAPOR DIAMETER
  1.0000 PIPE LENGTH OUTSIDE MEACTOR 95.26 VAPOR AREA. MM++2
  1.4782 TOTAL HEAT PIPE LENGTH
  1.5772 DUERALL REACTORTHEAT RIPE LENGTH
REACTOR WEIGHTS: KILDGRAMS
             190.4 FUEL: U235 MASS # 161.8
             310.7
                   PERLECTOR
             200.3 HEAT PIPES, MT/UNIT LENGTH (MG/M) # 136.03
```

- 33.0 CONTROL SYSTEM (ASSUME CONSTANT # 33 Kg)
- 51.4 suppost staucture 7% or seactor ut)

<sup>785.7</sup> TOTAL PEACTOR + HEAT PIPES

 $<sup>81.56~{</sup>m MH/M} {
m MeS}$  and pour in fuguerace  $-9.52~{
m KM}$  equer see Heat size 99.93 MUZM++3.HTPIPE AXIAL HT FLUX - 0.750 MUZM+42.HTPIPE PAD HTPLX \*\*\*\*\*\*\*\*\*\*\*\*

#### \*\*\*\*\*\*\*\*\*\*\*\*\*\*

page no. 19 5-17-78 type new input: page, was 2 ... stop stop

```
(KCORE) (1.270c.002) CORE =UC
 4,000 (PP) PEACTOR FORERING
 1425. (THE) HEAT PIPE TEMPIDES K. (PREF) (1.8/SE-SED) PEFLECTOR PSED
 3650. (TIME) LIFETIME DAYS
                                 CMHP) (1:2:3/NE:MO:N) HEAT PIPE HMO
 1.00 (SUD) COME LYD MATIO
                                  (KUAROR) (1:2/LI:NA) VAROR
 10.0 (DAML) AXIAL HT FLUX; MUZCH2 (IDPTN) (1.2)
                                                              =2
                                                      OFTION
 200. (DTFMAX) MAX FUEL DELTA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
MOTER OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING : DODME(M) KREF(M) UNKT FRETA NPIPE ..STOP
NPIPE=264 STOP
            264
                (NPIPE) NO. OF HEAT PIPES
                                PKAPS BHIN
       BETA
            レビ
                   VED
                         ALFA
                                             DYMIN CORGAP ENDGAP
     0.600 0.004 0.050 0.600 1.500 0.050 0.030 0.015 0.005
 TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PRAVG=2. ETC ...STOP
*ETA=0.56 *TOP
FLD INDEX =
THE = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 pc = 0.196 0.208 0.230 0.260 0.299 0.352 0.437 0.585 0.943 ◆.
 p_{CH} = 0. 0. 0. 0. 1.512 0.567 0.416 0.344 0.300
* * * * * * * * * * * * * TYPE GO OR START OVER * * * * * * * * * * * *
GO. . ADJUST SETA FOR 10% SHELLING
BETA =0.5600 UNF =0.7415 UF =0.2585 DX =0.1000 DC =0.4863
REACTIVITY CHANGES: DELTA K
     suph = 0.03924 exp = 0.01764 sape = 0.02000 total = 0.07688
 FUEL ELEMENT MOLUME FRACTIONS
    CLADDING FUEL PEGION HEAT PIPE
                                        MALLTHICK
                                                    レムを自動
               0.5898
     0.0500
                            0.3602
                                       0.1441
                                                    0.2161
HEXAGONAL CORNER CORRECTION FACTOR #1.1546
NUMBER OF HEAT PIPES # 127.4595
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 264
 TEMPERATURE SUMMARY DEGREE MELVIN
     MAXIMUM FUEL DELTA T = 96.6
     ANG DELTA T ACCROSE HEAT PIPE WALL = 13.7
     AVERAGE FUEL TEMPERATURE =1470.9
     MAKIMUM FUEL TEMPERATURE #1542.2
 BURN FRACTION OF 0335 \pm 0.0654
Fission density (Fissions/cm++3) = 7.0546+20
FUEL SHELLING, MOLUME % = 10.05
HEACTOR DIMENSIONS METERS
                                   FUEL ELEMENT DIMENSIONS: MM
                                      28.45 WIDTH ACCROSS HEX FLATS
  0.4863 COME DIAMETER
  0.4863 COME HEIGHT
                                      29.87 EDUID. FUEL ELEMENT DIA
   0.7163 PEACTOR DIAMETER
                                      29.11 EQUIV. PUEL REGION O.D.
                                      17.92 HEAT PIPE G.D.
   0.6963 PEACTOR HEIGHT
                                      13.88 VAPOR DIAMETER
   0.1000 PEFLECTOR THICKNESS
  1.0000 PIPE LENGTH OUTSIDE PEACTOR 151.40 MAPOR AREA: HM++2
  1.5913 TOTAL HEAT PIPE LENGTH
  1.6963 OVERALL REACTOR HEAT PIPE LENGTH
 PERCTOR MEIGHTS: MILDSPAMS
            302.0 FUEL: U235 MASS = 256.7
            493.6 PEFLETTOR
            432.5 HEAT PIPES, MIZUNIT LENGTH (KG/M) = 271.80
             33.0 CONTROL SYSTEM (ASSUME CONSTANT # 33 KG
             88.3 SUPPORT STRUCTURE (7% OF REACTOR WT)
           1349.4 TOTAL REACTOR + HEAT PIPES
```

75.40 MUZM+43.AUG POWE IN FUELSPACE 15.15 MUSPOWER PER HEAT PIPE 100.08 MUZM+42.HTPIPE ANIAL HT FLUX 0.714 MUZM+42.HTPIPE PAD HTFLX ++++++++++

```
*****
  PROF NO. 1 5-18-78
                                                             TYPE NEW INPUT! PRE! . .. STOP
pes0.2 tup=1425. time=3650. kcope=5 kmep=2 ioptn=2 stop
  0.200 (PM) REACTOR POMER HM
                                                                                    (KCOPE) (1:2/UC:UO2) COPE #M060U02
  1425, (THE) HEAT ETER TEMP.DEG K. (KPEP) (1.2756.560) REFLECTOR FEED
  BASE, (TIME) LIFETINE DAYS (MAP) (1.2.3/NE MO H) HEAT PIPE END
                                                                                     (KUAPOR) (1.2/LI.NA) MAPOR
     1.00 (KLD) COME LID MATIO
                                                                                                                                                               10.0 (DAYL) ANTAL HT FLUX+KH/CM2 (IDPTN) (1+2)
                                                                                                                                                                =2
                                                                                                                                        DPTION
     200. (STEMAR) HAR FUEL DELTA TYDES K
     1.00 (MEL1) PIPE EXTENSION H
  NOTE: OFTIONS ARE I 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
     TYPE IN ANY OF FOLLOWING : DOORE(M) WREE(M) WHET FRETA NPIPE ..STOP
NPIPE=84 FTOP
                                            (NPIPE) NO. OF HEAT PIPES
                                                    VCD
                                                                                 PKANG BHIN
                   BETA
                                  いご
                                                                    ALFA
                                                                                                                    DYMIN CORGAP ENDGAP
                                                 0.050 0.600 1.500 0.050 0.030 0.015 0.005
              0.100 0.
     TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
νc=0.012 νcσ=0. στορ
  FLD INDEX =
  v_{NF} = 0.100 \, 0.200 \, 0.300 \, 0.400 \, 0.500 \, 0.600 \, 0.700 \, 0.800 \, 0.900 \, 1.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.000 \, 0.0
    pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
  n_{CH} = 0. 0.207 0.142 0.115 0.099 0.088 0.081 0.074 0.070 0.066
ullet 
  pera = 0.1000 vas = 0.1501 vs = 0.8499 pr = 0.1000 pc = 0.3115
  REACTIVITY CHANGES, DELTA K
              FURN = 0.00464 EXP = 0.01274 EAFE = 0.02000 TOTAL = 0.03738
  FUEL FLEMENT MOLUME FRACTIONS
            にいわりている
                                       FUEL PEGION
                                                                         HEAT PIPE
                                                                                                      MALLTHICK
                                                                                                                                    VAPOR
                                            0.9558
                                                                       0.0442
                                                                                                      0.0177
                                                                                                                                    0.0265
  MEXAGONAL CORNER CORRECTION FACTOR #1.0020
  NUMBER OF HEAT PIPER = 31.5836
       MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES #
                                                                                                                                                    24
  TEMPERATURE SUMMARY DEGREE KELVIN
              MAXIMUM FUEL DELTA T = 75.2
              ANG DELTA T ACCROSS HEAT PIPE WALL # 3.4
              AMERAGE FUEL TEMPERATURE #1453.4
              MAXIMUM FUEL TEMPERATURE #1505.3
  EURN FRACTION OF US35 #0.0077
  FISSION DENSITY (FISSIONS/CM++3) = 8.345e+19
  FIRE FUELLING-VOLUME 2 = 0.
  NEACTOR DIMENSIONS, METERS
                                                                                          FUEL ELEMENT DIMENSIONS. HM
       0.3115 COME DIAMETER
                                                                                                 32.18 WIDTH ACCROSS HEX FLATS
       0.3115 come нетонт
                                                                                                 33.79 EQUIV. FUEL GLEMENT DIA
       0.5415 PEACTOR DIAMETER
                                                                                                 33.79 EQUIV. FUEL REGION D.D.
       0.5215 PEACTOR HEIGHT
                                                                                                    7.11 HEAT PIPE G.D.
                                                                                                   5.51 VAPOR DIAMETER
       0.1000 PEFLECTOR THICKNESS
       1.0000 PIPE LENGTH DUTSIDE MEACTOR
                                                                                                 23.80 VAPOR AREA: MM++2
       1.4165 TOTAL HEAT PIPE LENGTH
       1.5215 DUERALL PEACTOR HEAT PIPE LENGTH
  MEACTOR MEIGHTS: MILDSRAMS
                               214.3 FUEL: 0235 MASS = 108.7
                               240.2
                                               PEFLECTOR
                                  19.3
                                               HEAT PIPES: WT/UNIT LENGTH (MG/H) = 13.60
```

33.0 control system (assume constant =  $33 \, \text{kg}$ ).

35.5 support structure (7% or reactor ut)

548.8 TOTAL PRACTOR + HEAT PIRES

 $8.92~\mathrm{MpcM++3}$  and four in furtspace  $-2.38~\mathrm{Mpcfourp}$  for heat pipe. 100.04 MU/Mullet2.HTPIPE AKIAC HT FCUK = 0.442 MU/Mullet2.HTPIPE PAD HYPEK \*\*\*\*\*\*\*\*\*\*\*\*\*

```
OF POOR CHANNEY
G47
                          -----
                         TYPE NEW INPUT: PRE1. KHP#2 ... STOP
PROT NO. 2 5-18-78
PRED.4 ETOP
                                  (Kopes) (1.2/Uc.up2) come = #Np60up2
 0.400 (PP) BEACTOR POWER NO
 1425. (THP) HEAT PIPE TEMP*DEG M. (MARE) (1.278E:SEG) MEFLECTOR PRO
 3650. (TIME) LIFETIME, DAYS
                                  (KHP) (1:2:3/NE:MO:H) HEAT FIFE FMO
                                  (KUAPOR) (1.27LI:NA) VAPOR
 1.00 (BLD) COME L/D MATIO
 10.0 (DAYL) ASIAL HT FLUKSFUSCHE (IOPTN) (1:2)
                                                                =2
 200. (DIFMAY) MAY FUEL DELTA TIDES H
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS AND 1 1-CODE PT DESIGN. 2-SPECIFIED DESIGN
 TYPE IN ANY OF POLLOWING ! DCORE(M) YREF(M) UNFT FEETA NPIPE ..STOP
NPIPE#84 STOP
             84
                 (NPIPE) NO. OF HEAT PIPES
       PETA
              175
                   VCD
                         再し世界 一世代典化学 をかまり
                                               DYMIN CORGAP ENDGAP
 0.100 0.012 0. 0.600 1.500 0.050 0.080 0.015 0.005
TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
 TED THIDEY F
 PMF = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 p_{GH} = 0. 0.293 0.201 0.163 0.140 0.125 0.114 0.105 0.098 0.093
30
              UNE =0.1848
                            \nu_F = 0.8152 px = 0.1000
RETA = 0.1000
                                                     pc =0.3214
 PEACTIVITY CHANGES, DELTA M.
     suggests = 0.00881 see = 0.01274 sees = 0.02000 total = 0.04155
 FUEL ELEMENT POLUME PRACTIONS
                             HEAT PIPE
                                         HALL+HICK
    CLADDING
               FUEL PERION
                                                     VAPOR
                 0.9167
                             0.0333
                                                     0.0500
     0.
                                        0.0333
 HEXAGONAL CORNER CORRECTION FACTOR =1.0070
 NUMBER OF HEAT PIPES = 46.5570
  MINIMUM PRACTICAL (OR SESCIPIED) NUMBER OF MEAT PIPES #
 TEMPERATURE SUMMARY DEGREE MELVIN
     MAXIMUM FUEL DELTA T = 110.8
     ANG DELTA T ACCEPTED HEAT PIPE NALL #
     вививав виви темрератире ≃1468.5
     MAXIMUM FUEL TEMPERATURE #1545.7
 BURN EMACTION OF 0.235 \pm 0.0147
 Fission density (Fissions/cm+3) = 1.585e+20
 FUEL SUFLLING PROLUME % = 0.
 REACTOR DIMENSIONS, METERS
                                   FUEL ELEMENT DIMENSIONS - MM
   0.3214 ddms blanstsm
                                       33.19 WIDTH ACCRUSE HEX MUNTE
   0.3214 COME HEIGHT
                                       34.85
                                             EDUIV. FUEL ELEMENT DIA
   0.5514 REACTOR DIAMETER
                                       34.85 EQUIV. FUEL PEGION D.D.
   0.5314 PEACTOR HEIGHT
                                       10.06
                                             HEAT PIPE D.D.
   0.1000 PEPLETTOR THICKNESS
                                        7.79
                                             VAPOR DIAMETER
   1.0000 PIPE LENGTH OUTSIDE REACTOR
                                       47.66
                                             - 心内中四尺 内界医内。 MM442
   1.4264
          TOTAL HEAT PIPE LENGTH
   1.5314 DIVERALL REACTOR HEAT PIPE LENGTH
 REACTOR NEIGHTS: MILDSPAMS
```

```
225.6 FUEL: U235 MASS # 114.4
251.9
      PEFLECTOR
 38.8 HEAT PIPES: WT/UNIT LENGTH (KG/M) = 27.22
 33.0 conteol system (assume constant = 33 kg)
 38.5 suppost staucture (7\% of seactor with
```

587.9 TOTAL PEACTOR + HEAT PIPES

16.94 MUZMAABAADA POUR IN FUELSPACE 4.76 KUSPONER PER HEAT PIPE 99.92 MN/M++2.HTPIPE AVIAL HT FLUX - 0.605 MN/M++2.HTPIPE PAD HTPLX \*\*\*\*\*\*

```
*******
```

```
5-18-78
                        TYPE NEW INPUT: PRE1. MMPE2 ...STOP
FROE NO. 3
PRED. 7 ETDP
 0.700 (PA) PEACTOR POHER MH
                                 - (Krome) (1.2/uc.uo2) come = #Mg60ug2
 1425. (THP) HEAT PIPE TEMPIDES H. (KPEP) (1:2/98:980) REPLECTOR PAGE
 3650. (TIME) LIPETIME DAYS
1.00 (RLD) COME L/D MATIO
                                  (KHP) (1:2:3/NE:MO:W) HEAT PIPE BMD
                                   (KUAPOR) (1:2/LI:NA) VAPOR
                                                                #MA
  10.0 (maxi) Akial HT FLUKYMHZCH2 (IDFTN) (1:2)
                                                       OPTION
                                                                 =2
 200. (DIPMAY) MAY PURE DELTA TIDES K
  1.00 (HPL1) PIPE EXTENSION M
NOTE: OFF ONE ARE ! 1-CODE PT DESIGN: 2-specified Design
  TYPE IN ANY OF FOLLOWING : DCORE(M) YREF(M) UNFT FRETA NPIPE ..STOP
NPIFEE120 STOP
             120 (NPIPE) NO. OF HEAT PIPES
              UC UCD ALFA PKAUG BMIN
                                               DXMIN COMBAR ENDOAR
        BETA
                          0.600 1.500 0.050 0.080 0.015 0.005
     0.100 0.012 0.
  TYPE: STOP, OR NEW CONSTANTS IE, VC=0, PKANG=2, ETC ...STOP
vc=0.008 stop
 FLD INDEX #
 \nu_{\rm MF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  pc = 0.299 0.324 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 p_{CH} = 0. 0.380 0.263 0.214 0.184 0.165 0.150 0.139 0.130 0.122
* * * * * * * * * * * * * * TYPE GO ON STANT OVER * * * * * * * * * * * * * * *
1301
 EQTA = 0.1000 UNF = 0.2264 UF = 0.7736 DX = 0.1000 DC = 0.3348
PERCTIVITY CHANGES. DELTA M.
     2000 = 0.01435 \text{ exp} = 0.01274 \text{ same} = 0.02000 \text{ total} = 0.04709
 FUEL ELEMENT VOLUME FRACTIONS
    CLADDING
               FUEL PEGION HEAT PIRE
                                         MALL+MICK
                                                     VAPOR
                                         0.0534
     0.
                 0.8665
                             0.1335
                                                     0.0801
HEMARGNAL CORNER CORRECTION FACTOR #1.0180
PRIMPRIA DE MENT PIPES # 61.1476
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 120
 MAKEMUM FUEL DELTA T = 101.9
     AND DELTA T ACCESSE MEAT PIPE MALL # 7.7
     AUSPAGE FUEL TEMPSPATURE #1466.7
     MARINUM FUEL TEMPERATURE =1538.4
 BURN FRACTION OF 0.235 \pm 0.0239
 Fission Density (Fissions/cm++3) = 2.584e+20
 FUEL FUELLING-MOLUME 3 = 0.
 REACTOR DIMENSIONS, METERS
                                    FUEL ELEMENT DIMENSIONS: HM
   0.3348 come blanetem
                                       29.00 WIDTH ACCROSS HEX FLATS
   0.3348
          COPE HEIGHT
                                       30.44
                                              EDUTY. FUEL ELEMENT DIA
   0.5648 PEACTOR DIAMETER
                                       30.44 EQUIV. FUEL MEGION O.D.
   0.5448 PERCTOR HEIGHT
                                       11.12 HEAT PIN. O.D.
   0.1000 PEFLECTOR THICKNESS
                                       8.62 VAPOR DIAMETER
  1.0000 PIPE LENGTH OUTSIDE PEACTOR 58.31 VAPOR AREA: MM++2
   1.4398 TOTAL HEAT PIPE LENGTH
   1.5448 DIVERALL REACTOR-HEAT RIFE LENGTH
 PERCYCLA METGHTS: MILDGRAMS
            242.3 FUEL: 0235 MASS = 122.8
            268.5 REFLECTOR
             68.5 Hear Hipees NT/ONIT LENGTH (VOVM) # 47.58
              33.0 CONTROL SYSTEM (ASSUME CONSTANT # 33 KG)
             42.9 support structure (7% or reactor ut).
            655.2 TOTAL PEACTOR + HEAT PIPES
  27.62 NUZN++3.605 POUR IN FUELSPACE 5.83 NUMPOUER PER HEAT PIPE
```

100.05 NUZM+68-HTRIRE AKIAL HT FLUX - 0.644 NUZM+6-8-HTRIRE RAD HTFLX

T.EE AN DO STOP

#### \*\*\*\*\*\*\*\*\*\*\*\*\*

PROB NO. 4 5-18-78 TYPE NEW INPUT: PRE! KHPE2 ... STOP PREI. STOP

1.000 (PM) PRACTOR POWER: NW (KCOPE) (1:2/UC:UD2) CD:E =MD60UD2 1425. (THP) HEAT PIPE TEMP+DEG K (KREF) (1.2/BE:SED) REFLECTOR #BED 3650. (TIME) LIPETIME DAYS (KHP) (1:2:3/NB; MO:N) HEAT PIPE =MO 1.00 (FLD) COME L/D MATIO (KUAPOR) (1,2/LI,NA) VAPOR 10.0 (DAYL) AYIAL HT FLUXIKH CM2 (IDPTN) (1:2) OPTION

200. (DTFMAK) MAK FUEL DELTA TIDES K

1.00 (HPL1) PIPE EXTENSIONSM

NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN TYPE IN ANY OF POLLOWING : DOUBE(M) MEER(M) UNET ESETA NPIPE ..STOP NPIPE=162 STOP

162 (NPIPE) NO. OF HEAT PIPES

BETA VC VCD ALTA PKAVG BMIN DYMIN COMMAR ENDGAP 0.100 0.008 0. 0.600 1.500 0.050 0.080 0.015 0.005 Type: Stop: OR NEW CONSTANTS IE. VC=0. PKANGE2. ETC ...Stop vc=0.006 stop TUD INDEX #

 $v_{NF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000$ pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 +.

 $p_{CH} = 0.$  0.449 0.313 0.255 0.220 0.197 0.179 0.166 0.155 0.146 + + + + + + TYPE GO OF START DUER + + + + + + + + + + + 430

UNF =0.26%? 367A = 0.1000pc =0.3482 PERCTIVITY CHANGES: DELTA K

BUPN = 0.01915 EXP = 0.01274 SAFE = 0.02000 TOTAL = 0.05139FUEL ELEMENT MOLUME FRACTIONS

CLADDING FUEL PEGION HEAT PIPE おみたしずいまでは 0.0705 0.8238 0.1762 0. 0.1057

HEXAGONAL CORNER CORRECTION FACTOR #1.0315

NUMBER OF HEAT PIPES = 71.2219

MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 162

TEMPERATURE SUMMARY DEGREE MELVIN

MAXIMUM FUEL DELTA T = 87.9

ANG DELTA T ACCROSS HEAT PIPE WALL # 7.8

AVERAGE FUEL TEMPERATURE =1462.1

MAXIMUM FUEL TEMPERATURE =1524.7

PURN FRACTION OF  $0235 \pm 0.0319$ 

Fission Density (Fissions/CM++3) = 3.447e+20

FUEL SWELLING PUBLISHE % = 0.

PERCTOR DIMENSIONS, METERS FUEL ELEMENT DIMENSIONS: MM 0.3482 CORE DIAMETER 25.97 WIDTH ACCEDS HEX FLATS 0.3482 COME HEIGHT 27.27 EQUIV. FUEL ELEMENT DIA 27.27 EQUIV. FUEL REGION C.D. 0.5782 PEACTOR DIAMETER 0.5582 MEACTOR HEIGHT 11.45 HEAT PIPE D.D. 0.1000 PEFLECTOR THICKNESS 8.87 VAPOR DIAMETER 1.0000 PIPE LENGTH OUTSIDE MEACTOR 61.74 VAPOR AREA, MM++2 1.4532 TOTAL HEAT PIPE LENGTH 1.5588 OVERALL REACTOR+HEAT PIPE LENGTH

PEACTOR MEIGHTS: MILOGRAMS

259.4 FUEL: U235 MASS = 131.5

285.5 PEFLECTOR

98.8 HEAT PIPES, WT/UNIT LENGTH (KG/M) = 68.0233.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 kg)

47.4 SUPPORT STRUCTURE (7% OF REACTOR WT)

724.1 TOTAL PEACTOR + HEAT PIPES

36.84 MN/M++3+AVG POWR IN FUELSPACE -6.17 KW+POWER  $\pm 1.7$  MEAT PIPE 99.98 MU/M++2.HTPIPE AXIAL HT FLUX - 0.637 MU/M++2.HYPIPE PAD HTPLX \*\*\*\*\*\*

9.52 KWIPDWER PER MEAT PIRE

```
5-18-78
                                            TYPE NEW INPUT: PREI. KHPES ... STOP
PM#2. STOP
 2.000 (PP) REACTOR POWER MU
                                                            (KCOME) (1:2/UC:UD2) CDME #MD60UD2
  1425. (THE) HEAT PIPE TEMPIDES K
                                                            (KREE) (1:2/se:sed) PAPLECTOR ASED
  3650.
           (TIME) LIFETIME, DAYS
                                                            (KHP) (1:2:3/NB:MD:W) HEAT PIPE MMD
   1.00 (SLD) CORE L/D PATIO
                                                            (KUAPOR) (1.2/LI.NA) VAPOR
                                                                                                                ENA
   10.0 (DAYL) AYIAL HT FLUX: KW/CM2 (IOPTN) (1:2)
                                                                                               DETION
                                                                                                                ≖≥
   200. (DIFMAX) MAY FUEL DELTA TIDES K
   1.00 (HPL1) PIPE EXTENSION M
 NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
   TYPE IN ANY OF FOLLOWING : DCDRE(M) WREE(M) WHET FRETA NPIPE ... 2TOP
NPIPE#210 STOP
                      210
                             (NPIPE) NO. OF HEAT PIPES
             RETA
                         UC.
                                   VCD
                                               ALFA
                                                         PRHING BMIN
                                                                                 DXMIN CORGAP ENDGAP
                                              0.600 1.500 0.050 0.080 0.015 0.005
          0.100 0.006 0.
   TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAUG=2. ETC ...STOP
υσ=0.005 stop
                           3
 ELD INDEX #
 \nu_{NF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
   pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 p_{GH} = 0. 0.632 0.442 0.360 0.311 0.273 0.253 0.234 0.219 0.207
                 lacktriangled lac
GO.
                                                  \nu = -0.6434
                        UNE 40.3566
                                                                        p \times = 0.1000
                                                                                            pc ≖0.3893
 BETA = 0.1000
 PEACTIVITY CHANGES. DELTA K
          pupm = 0.03138 \text{ exp} = 0.01274 \text{ safe} = 0.02000 \text{ total} = 0.06412
 FUEL ELEMENT VOLUME FRACTIONS
                                                  HEAT PIPE
                                                                       MALL+MICK
                           FUEL PEGION
                                                                                           VARDE
        CLADDING
                                                   0.2815
                              0.7185
                                                                       0.1126
                                                                                            0.1689
          0.
 HEXAGONAL CORNER CORRECTION FACTOR =1.0825
 NUMBER OF HEAT PIPES # 92.2398
    MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 210
 TEMPERATURE SUMMARY DEGREE MELVIN
         MAXIMUM FUEL DELTA T = 87.8
          AMB DELTA T ACCROSS HEAT PIPE WALL = 10.8
          AVERAGE FUSL TEMPERATURE =1465.1
         MAKIMUM PUFL TEMPERATURE #1529.0
 BURN FRACTION \alpha = 0.335 \pm0.0523
 Fission Density (Fissions/CM++3) = 5.648e+20
 FUEL SWELLING MOLUME % = 0.
                                                             FUEL ELEMENT DIMENSIONS, MM
  PEACTOR DIMENSIONS, METERS
                                                                    25.52 WIDTH ACCROSS HEX FLATS
     0.3893 CORE DIAMETER
     0.3893
                 CORE HEIGHT
                                                                    26.80 EQUIV. FUEL ELEMENT DIA
                                                                    26.80 EQUIV. FUEL REGION C.D.
     0.6193 REACTOR DIAMETER
     0.5993 PEACTOR HEIGHT
                                                                    14.22 HEAT PIPE O.D.
     0.1000 PEFLECTOR THICKNESS
                                                                    11.01
                                                                               VAPOR DIAMETER
     1.0000 PIPE LENGTH OUTSIDE PEACTOR
                                                                   95.26 MARGA AREA: MM++2
     1.4943
                 TOTAL HEAT PIPE LENGTH
     1.5993 OVERALL REACTOR*HEAT PIPE LENGTH
 PEACTOR MEIGHTS. MILDSPAMS
                      316.6 FUEL: U235 MASS = 160.5
                      341.3 PEFLEITOR
                      203.3 HEAT PIPES: WIZUNIT LENGTH (KGZM) = 136.03
                       33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 kg)
                       62.6 SUPPORT STRUCTURE (7% OF REACTOR WT)
                      956.7 TOTAL REACTOR + HEST PIPES
```

99.98 MW/M++2+HTPIPE AYIAL HT FLUX 0.707 MW/M++2+HTPIPE PAD HTFLX

A0.37 NUZM++3+AMS POWE IN FUELSPACE

```
***************
```

```
₽₩0₽ NO. 5 5-18-78
                          TYPE NEW INPUT: PRE1. KHORS ... STOP
PPE4. ETOP
                                    (Mcome) (1,2/UC:UD2) come = #MD60UD2
4.000 (PP) PEACTOR POWER MA
 1425. (THP) HEAT PIPE TEMP DEG K (KREF) (1.2/8/ PEO) PEFLECTOR ABED
                                    (KHP) (1.2.3/Norm TH) HEAT PIPE AND
 3650. (TIME) LIFETIME DAYS
  1.00 (SUD) CORE LYD MATIO
                                    (KNAPOR) (1.2/LISM) PAROR
                                                                    = 1.1
  10.0 (DAYL) AKIAL HT FLUY-KWYCMZ (IDPTN) (1.2)
                                                         OFTION
  200. (DIEMAK) MAY FUEL DELIA TYDEG K
  1.00 (HPL1) FIRE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DCORE(M: MREF(M) WHAT FRETA NATRE ...STOP
NPIPERSON STOP
             266 (NPIPE) NO. OF HEAT PIPES
        EETA
              いこ
                     MCD
                            ALFA
                                   PRANG ENTN
                                                  DYMIN CORGAD ENDGAP
                           0.600 1.500 0.050 0.080 0.015
      0.100 0.004 0.
  TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKANG=2. ETC ...STOP
STOP
 BLD INDEX =
₽N# = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
  pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
nch = 0. 0.890 0.624 0.508 0.439 0.392 0.358 0.331 0.310 0.292
          lacktriangle lacktriangle lacktriangle lacktriangle lacktriangle lacktriangle lacktriangle lacktriangle lacktriangle lacktriangle
30
                              v≓ =0.5280
meta = 0.1000
               v_{\rm NF} = 0.4720
                                          p \times = 0.1000 p \in = 0.4554
REACTIVITY CHANGES! DELTA K
      suph = 0.04777 sxp = 0.01874 sape = 0.02000 total = 0.08051
FUEL FLEMENT VOLUME FRACTIONS
                FUEL PESION
                              HEAT PIPE
                                           MALL+WICK
                                                       VAROR
    CLADDING
                  0.5890
      0.
                               0.4110
                                           0.1644
                                                       0.2466
MEYAGONAL CORNER CORRECTION FACTOR =1.1840
Number of Heat Piecs = 115.0234
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 266
TEMPERATURE SUMMARY DESPET MELVIN
     MAKIMUM FUEL DELTA T = 86.5
      AUG DELTA T ACCROSS HEAT PIPE WALL = 14.6
      AMERAGE FUEL TEMPERATURE =1468.4
     MAKEMUM FUEL TEMPERATURE =1533.3
BURN FRACTION OF U235 =0.0796
Fission Density (Fissions/ch+43) = 8.598e+20
FUEL SHELLING PROLUME % = 0.
PERCTOR DIMENSIONS: METERS
                                      FUEL FLEMENT DIMENSIONS, MM
   0.4554 COME DIMMETER
                                         26.54 NIDTH ACCROSS HEW FLATS
   0.4554 CORE HEIGHT
                                         27.87
                                                EDUIV. FUEL ELEMENT DIA
   0.6854 REACTOR DIAMETER
                                         27.87
                                               EQUIN. FUEL PEGION O.D.
   0.6654 REACTOR HEIGHT
                                         17.87
                                                HEAT PIPE U.D.
   0.1000 PERLECTOR THICKNESS
                                        13.84 VAPOR DIAMETER
  1.0000 PIPE LENGTH DUTSIDE REACTOR 150.41
                                                MARCH AREA. MM++2
  1.5604 TOTAL HEAT PIPE LENGTH
   1.6654 DIMERALL REACTOR THEAT PIPE LENGTH
PEACTOR MEIGHTS: MILDSPAMS
             416.0 FUEL: 0235 MASS = 210.9
             448.0
                    PEFLECTOR
             424.5 HEAT PIPES, WT/UNIT LENGTH (KG/M) = 272.05
              33.0 control system (assume constant = 33 \text{ kg})
              98.1 SUPPORT STRUCTURE (7% OF REACTOR WT)
            1407.5 TOTAL PEACTOR + HEAT PIPES
 91.91 MUZM++3.APG POWR IN FUELSPACE 15.04 MU.FOWER PER HEAT PIPE
 99.93 MUZMullet+3.HTPIPE AVIAC HT PCUX =0.760 MUZMulletAHTPIPE PAD HTPLX
```

```
******
```

```
PHOP NO. 9 5-18-78
                         TYPE NEW INPUT: PART, KHPE2 ...STOP
PRE0.2 THRE1600, KNAPORE1 STOR
                              (Kcome) (1.270c.0g2) come #Mo600g2
 0.200 (pm) mgactom mouse, No.
 1600. (THP) HEAT PIPE TEMP+DEG K (KREF) (1,2/BE,BED)
                                                       PEFLECTOR FRED
 3650. (TIME) LIFFTIME DAYS
                                  (KHP)(1.2.3/NE-MO-W) HEAT PIPE FMO
  1.00 (FUD) CORE L/D MATIO
                                   (KMAROR) (1,27LI,NA) MAROR -
                                                                 =LI
  10.0 (DAYL) AKIAL HT FLUKKRIZCHE (IDPTN) (1.2)
                                                       DPTION
                                                                 =5
  200. (DIFMAX) MAX FUEL DELTA TIDEG K
  1.00 (MPL1) PIPE EXTENSION M
 NOTE: OPTIONS ARE: 1-CODE PT DESIGN: 2-specified design
  TYPE IN ANY OF FOLLOWING : DCORE(M) WREE(M) UNET FRETA NPIPE .. STOP
NPIPERS4 STOP
             84
                  (NPIPE) NO. OF HEAT PIPES
              VC VCD ALFA PKAVG BMIN
       RETA
                                               DXMIN CORGAP ENDGAP
     0.100 0.004 0.
                          0.600 1.500 0.050 0.030 0.015 0.005
  TYPE: STOP: OR NEW CONSTANTS IE, MC=0, PKAMG=2, ETC ...STOP
\psi_{C}=0.018 stop
 SLD INDEX =
\nu_{\rm NF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 p_{CH} = 0. 0.207 0.142 0.115 0.099 0.088 0.081 0.074 0.070 0.066
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ↑ TYPE GO ON START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
30
pera =0.1000 \nu_{NF} =0.1501 \nu_{F} =0.8499 p_{X} =0.1000 p_{C} =0.3115
REACTIVITY CHANGES! DELTA K
     supple = 0.00464 sep = 0.01456 seps = 0.02000 total = 0.03920
 FUEL FLEMENT VOLUME FRACTIONS
                           HEAT FIFE
               FUEL REGION
                                         MALLTWICK
                 0.9558
                             0.0442
                                         0.0177
     Ñ.
                                                     0.0265
HEXAGONAL CORNER CORRECTION FACTOR =1.0020
NUMBER OF HEAT PIPES = 31.5836
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES F
 TEMPERATURE SUMMARY DEGREE MELMIN
     MAKIMUM FUEL DELTA T = 75.2
     ave belta i accedse Heat Pies Wall = 3.4
     AMERAGE FUEL TEMPERATURE =1628.4
     MAKIMUM FUEL TEMPERATURE =1680.3
 BURN FRACTION OF 0.235 \pm 0.0077
 Fishion Density (Fissions/cm++3) = 8.345e+19
 FUEL SMELLING+MOLUME % = 0.
 PEACTOR DIMENSIONS: METERS
                                   FUEL ELEMENT DIMENSIONS, MM
   0.3115 CORE DIAMETER
                                       32.18 WIDTH ACCROSS HEX FLATS
   0.3115 comm Height
                                       33.79 EQUIV. FUEL ELEMENT DIA
   0.5415 PEACTOR DIAMETER
                                       33.79 EDUIN. FUEL REGION O.D.
   0.5015 PEACTOR HEIGHT
                                        7.11 HEAT PIPE O.D.
   0.1000 PERCECTOR THICKNESS
                                        5.51
                                              VARDR DIAMETER
   1.0000 PIPE LENGTH DUTSIDE PEACTOR 23.80 MAPOR AREA. MMF+3
   1.4165
          TOTAL HEAT PIPE LENGTH
   1.5815 OMERALL REACTOR THEAT PIPE LENGTH
 PEACTOR NEIGHTS: KILOGRAMS
            214.3 FUEL, 0235 MASS = 108.7
            240.2 PEFLECTOR
             19.3 HEAT PIPES: NT/UNIT LENGTH (MG/M) = 13.60
             33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)
             35.5 SUPPORT STRUCTURS (7% OF REACTOR WT)
            542.2 TOTAL PRACTOR + HEAT PIPES
```

8.9° MU/M++3, AVG ROUR IN FUELSPACE 2.38 KU:POUER REP HEAT RIRE 100.04 MU/Mullet2.HTRIPE AVIAL HT FLUY -0.442 MU/Mullet2.HTRIPE PAD HTFLY \*\*\*\*\*\*\*\*\*\*\*\*\*

```
PROP NO. 10 5-18-78
                         TYPE NEW INPUT: PREI. KHPE2 ...STOP
P##0.4 ETOP
 0.400 (PP) REACTOR POWER: NU
                                  (Kopes) (1.270c)/02) cope = =mp60up2
```

1600. (THE) HEAT SISS TEMP DEG K (KRES) (1,2/85 860) RESLECTION ARED 3650. (TIME) LIFETIME DAYS (KHP) (1:2:3/NE:MO:W) HEAT PIPE #MD 1.00 (FLD) CORE L/D PATIO (KNAPOR) (1:2/LI:NA) NAPOR =LI 10.0 (DAYL) AYIAL HT BLUX: KN/CH2 (IDPTN) (1:2) DPTION **=**2

200. (DIFMAX) MAX FUEL DELIG TIDES K

1.00 (HPL1) PIPE EXTENSION M

NOTE: OPTIONS ARE: 1-code PT DESIGN: 2-specified Design

TYPE IN ANY OF FOLLOWING : DOORE (M) WARF (M) PART FRETA APIPE .. STOP NPIPE=84 STOP

> 84 (NPIPE) NO. OF HEAT PIPES

MC. ALEA PRAMS BMIN RETA いにも DYMIN CORCAR ENDIAR 0.600 1.500 0.050 0.080 0.015 0.005 0.100 0.012 0. TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP STOP

SED INDEX =  $v_{\rm NF}$  = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000 pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆. bch = 0. 0.293 0.201 0.163 0.140 0.125 0.114 0.105 0.098 0.093 + + + + + + TYPE 50 OR START DMER + + + + + 30

**BETA** = 0.1000 UNF = 0.1848v = 0.8152 px = 0.1000 pc = 0.3214 REACTIVITY CHANGES. DELTA K.

**EVEN = 0.00881 EXP = 0.01456 SAFE = 0.02000 TOTAL = 0.04337** FUEL ELEMENT MOLUME FRACTIONS

FUEL PEGION HEAT FIRE CLADDING NALL+WICK MARCR 0.91670.08330.0333 0.0500

MEXAGONAL CORNER CORPECTION FACTOR =1.0070 NUMBER OF HEAT PIPES = 46.5570

MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES T

TEMPERATURE SUMMARY DESPES RELUIN

MAXIMUM FUEL DELTA T = 110.8

AVG DELTA T ACCROSS HEAT PIPE WALL # 6.5

AMERAGE FUSL TEMPERATURE =1643.5

MAXIMUM FUEL TEMPERATURE =1720.7

BURN FRACTION OF  $0235 \pm 0.0147$ 

Fishion density (Fissions/cm++3) = 1.585  $\pm$ 420

FUEL ENELLING . MOLUME % = 0.

#### REACTOR DIMENSIONS: METERS FUEL LEMENT DIMENSIONS, 4M 0.3214 come blametem 33.19 WIDTH ACCROSS HEX FLATS 0.3214 сора нетант 34.85 EQUIV. FUEL ELEMENT DIA 0.5514 реастор ріаметер 34.85 EDUIV. FUEL REGION O.D. 0.5314 PEACTOR PEIGHT 10.06 HEAT FIFE O.D. 0.1000 PEFLECTOR THICKNESS 7.79 PAPOR DIAMETER 1.0000 PIPE LENGTH OUTSIDE REACTOR 47.66 MAPOR AREA. MM++2 1.4864 TOTAL HEAT PIPE LENGTH 1.5314 OMERALL REACTORPHEAT PIPE LENGTH

## REACTOR MEIGHTS: KILDGRAMS

225.6 FUEL: U235 MASS = 114.4

251.9 PEFLECTOR

38.8 HEAT PIPES, NT/UNIT LENGTH (KG/M) = 27.22

33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 kg)

38.5 SUPPORT STRUCTURE (7% OF REACTOR NT)

587.9 TOTAL REACTOR + HEAT PIPES

16.94 MU/M++3.AMS POWE IN FUELSPACE 4.76 KHIPOWER PER HEAT PIPE 99.92 MUZM++2.HTPIPE AXIAL HT FLUX - 0.605 MUZM++2.HTPIPE PAD HTFLX \*\*\*\*\*\*\*

```
************
```

```
PROB NO. 11 5-18-78
                          TYPE NEW INPUT: PRE! KHPE2 ... ITOP
P#=0.7 STOP
 0.700 (sp) peactor pours_{
m MN} _{
m MN}
                                    (kcame) (1,2/uc,ua2) came **ma60ua2
 1600. (THP) HEAT PIPE TEMPIDES K. (MRSF) (1.2786.860) REFLECTOR FRED
 1600. (THE? HER) FIRE II.
3650. (TIME) LIESTINS:DAYS
                                    (KHP) (1.2.3/NE:MO:W) HEAT PIPE FMO.
  1.00 (ELD) COME L/D MATIO
                                     (KUAPOR) (1,2/LI,NA) VAPOR
                                                                     #LI
  10.0 (paxe) axial at plux, kn/cm2 (idptn) (1,2)
                                                          DETION
                                                                    =2
  200. (DIFMAY) MAY FUEL DELTA TYDEG K
  1.00 (HPL1) PIPE EXTENSION M
 NOTE, OPTIONS ARE: 1-cope PT DESIGN, 2-specified Design
  TYPE IN ANY OF FOLLOWING : DCORE(M) MREF(M) UNFT FRETA NPIPE ..STOP
NPIPE=120 STOP
             120 (NPIPE) NO. OF HEAT PIPES
                                                 DXMIN CORSAP ENDGAP
        BETA
              いさ
                     VCD ALFA
                                   アドランタ まみまり
                            0.600 1.500 0.050 0.080 0.015 0.005
      0.100 0.012 0.
  TYRE: STORE OR NEW CONSTANTS IE. VC=0. PMANG=2. ETC ...STOR

uc=0.008 stop
 SUD INDEX #
 \nu_{\text{NF}} = 0.100 \, 0.200 \, 0.300 \, 0.400 \, 0.500 \, 0.600 \, 0.700 \, 0.800 \, 0.900 \, 1.000
  pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 +.
 p_{CH} = 0. 0.380 0.263 0.214 0.184 0.165 0.150 0.139 0.130 0.122
          + + + + + + + TYPE GO OR START OVER + + + + + + + + + +
 BETA = 0.1000 UNF = 0.2264
                               ν⊭ =0.7736 | bx =0.1000 | bc =0.3348
 MENCHINITY CHANGES: DELTA K
      _{\rm BURN} \approx 0.01435 _{\rm EXP} \approx 0.01456 _{\rm SAFE} \approx 0.02000 _{\rm TOTAL} \approx 0.04891
 FUEL ELEMENT VOLUME FRACTIONS
                                                        VAPOR
                                            いらししていまだと
     CLADDING
                FUEL PEGION
                               HEAT FIFE
                   0.8665
                               0.1335
                                            0.0534
                                                        0.0801
 MEXAGONAL CORNER CORRECTION FACTOR #1.0180
 Number of HEAT PIPES = 61.1476
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 120
 TEMPERATURE SUMMARY DEGREE KELVIN
      MAKIMUM FUEL DELTA T = 101.9
      AMS DELTA T ACCROSS HEAT PIPE WALL # 7.7
      AUSPAGE FUEL TEMPERATURE =1641.7
      MAKIMUM FUEL TEMPERATURE =1713.4
 BURN FRACTION OF 0235 =0.0239
 Fission density (Fissions/ch+43) = 2.584e+20
 FUEL SUFLLING WOLUME % = 0.
                                      FUEL ELEMENT DIMENSIONS, MM
 EMBTEM FENDISHMENT HOTTONES
                                          29.00 WIDTH ACCROSS HEX FLATS
   0.3348 CCRF DIAMETER
   0.3348 ccas Height
0.5648 psactom Diametem
0.5448 psactom Height
                                          30.44
                                                EQUIV. FUEL ELEMENT DIA
                                          30.44 EQUIV. FUEL REGION O.D.
                                         11.12 HEAT PIPE O.D.
   0.1000 REFLECTOR THICKNESS
                                          8.62 MAPOR DIAMETER
   1.0000 Pipe Length outside peactor 58.31 vapor agea, MM++2
   1.4398 TOTAL HEAT PIPE LENGTH
   1.5448 OMERALL PEACTOR HEAT PIPE LENGTH
 REPOTER MEIGHTS: MILEGRAMS
             243.3 FUEL: U235 MASS = 122.8
             268.5 PEFLECTOR
               68.5 HEAT PIRES, WIYUNIT LENGTH (MG/M) = 47.58
               33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Mg)
              42.9 SUPPORT STRUCTURE (7% OF REACTOR NY)
              655.2 TOTAL REACTOR + HEAT PIPES
  27.62 MW/M++3+AUG POWE IN FUELSPACE
                                         5.83 KW-POWER PER HEAT PIPE
 100.05 MM/Mullet0.4TPIPE AxiAL HT FLUX -0.644 MM/Mullet0.4TPIPE PAD HTFLX
```

\*\*\*\*\*\*

```
*****
```

```
PROS NO. 12
               5-18-78
                          TYPE NEW INPUT: PRET, KAPES ... STOP
PRE1. STOP
                                  (KCORE) (1:2/UC:UO2) CORE =MO60UO3
 1.000 (PP) PEACTOR POWER MW
 1600. (THP) HEAT PIPE TEMP+DEG K (KREF) (1-2/se-sed) REFLECTOR #860
      (TIME) LIFETIME DAYS
                                   (KHP) (1:2:3/NE:MO:W) HEAT PIPE #MO
 3550.
  1.00 (SED) CORE L/D RATTO
                                   (KUAPOR) (1,2/LI,NA) VAPOR -
  10.0 (DAXL) AXIAL HT FLUM: KNZCM2 (IDPTN) (1:2)
                                                        DETION
                                                                  =2
  200. (DIFMAY) MAY FUEL DELTA TIDES K
  1.00 (HPL1) PIPE EXTENSION M
 NOTE: OPTIONS AME : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DOORE (M) MAER (M) MART FRETA NAIRE ... STOP
NPIPE=162 STOP
             162 (NPIPE) NO. OF HEAT PIPES
             VC VCD
                          ALEA PHAVE SMIN
                                                DXMIN CORGAN ENDGAP
        BETS
      0.100 0.008 0. 0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: STOP: OF NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
vc≈0.006 stop
SUD INDEX =
v_{NF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
  pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 рен = 0. 0.449 0.313 0.255 0.220 0.197 0.179 0.166 0.155 0.146
          ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
BETA =0.1000 VNF =0.2630 VF =0.7370 DX =0.1000 DC =0.3482
PRACTIVITY CHANGES, DELTA K
     puph = 0.01915 exp = 0.01456 same = 0.02000 total = 0.05371
FUEL ELEMENT VOLUME FRACTIONS
    CLADDING FUEL REGION HEAT PIPE WALL+WICK
                                                      い声を自身
                                         0.0705
                 0.8238
                             0.1762
                                                      0.1057
     n.
HEMAGONAL CORNER CORRECTION FACTOR =1.0315
NUMBER OF HEAT PIPES # 71.2219
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 162
TEMPERATURE SUMMARY DEGREE KELVIN
     MAXIMUM FUEL DELTA T = 87.9
     ANG DELTA T ACCROSS HEAT PIPE HALL # 7.8
     AMERAGE FUEL TEMPERATURE #1637.1
     MAKIMUM FUEL TEMPERATURE =1699.7
EURN FRACTION OF 0235 \pm 0.0319
Fission Density (Fissions/CM++3) = 3.447e+20
FUEL SWELLING MOLUME \% = 0.
PEACTOR DIMENSIONS! METERS
                                   FUEL ELEMENT DIMENSIONS! MM
                                        25.97 WIDTH ACCROSS HEX FLATS 27.27 EQUIV. FUEL ELEMENT DIA
   0.3482 COME DIAMETER
   0.3482 CORE HEIGHT
  0.5782 PEACTOR DIAMETER
0.5582 REACTOR HEIGHT
0.1000 REFLECTOR THICKNESS
                                        27.27 EDUIN. FUEL REGION O.D.
                                    11.45 HEAT PIPE O.D.
                                        8.87 VAPOR DIAMETER
  1.0000 PIPE LENGTH OUTSIDE PEACTOR 61.74 MAPOR AREA, MM++2
  1.4532 TOTAL HEAT PIPE LENGTH
   1.5582 OVERALL REACTOR+HEAT FIRE LENGTH
PEACTOR WEIGHTS: MILDSPAMS
             259.4 FUEL, 0235 MASS = 131.5
             285.5 PEFLECTOR
              98.8 HEAT PIPES: WIZUNIT LENGTH (KGZM) = 68.02
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)
             47.4 SUPPORT STRUCTURE (7% OF REACTOR WT)
```

724.1 TOTAL PEACTOR + HEAT PIPES

36.84 MM/M++3.4MG POWR IN FUELSPACE 6.17 KM.POWER PER HEAT PIPE 99.98 MUZM++3, HTPIPE ANIAL HT FLUX - 0.637 MUZM++2, HTPIPE PAD HTPLX \*\*\*\*\*\*

```
1.650 (PR) REACTOR POWER, MW (KCORE) (1,2/UC, UO2) CORE =MO60UO2
1600. (THP) HEAT PIPE TEMPIDES K (MREP) (1,2/38,380) REPLECTOR #360
3650. (TIME) LIFETIME:DAYS (MMP) (1:2:3/NB:MG:W) HEAT PIPE #MG
1.00 (FLD) CORE L/D BATIO (NVAPOR) (1:2/LI:NA) VAPOR #LI
 1.00 (SLD) CORE L/D RATIO
                                  (RVAPOR) (1,2/LI,NA) VAPOR =LI
 10.0 (DAXL) AXIAL HT FLUX; KH/CM2 (IDPTN) (1,2)
                                                                 =2
                                                        OPTION
 200. (DIFMAX) MAX FUEL DELTA TIDES K
 1.00 (MPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE: 1-CODE PT DESIGN; 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING : DCOPE(M) MARF(M) MAPT FRETA NAIRE ..STOP
NPIPESIGE STOP
            162 (NPIPE) NO. OF HEAT PIPES
       BETA VC
                   VCD
                          ALFA PKAVG BMIN
                                               DXMIN CORGAP ENDGAP
      0.100 0.
                    0.050 0.600 1.500 0.050 0.080 0.015 0.005
 TYPE: STOPE OR NEW CONSTANTS IE. VC=0. PKANG=2. ETC ...STOP
ESTA=0.1 MC=0.006 MCD=0. STOP
SLD INDEX # 3
v_{NF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
 pc ≈ 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
вен = 0. ).577 0.402 0.327 0.283 0.252 0.230 0.213 0.199 0.188
* * * * * * * * * * * * * * TYPE GO ON RESTART * * * * * * * * * * * * *
GO. . . PT DESIGN FOR PRES LAYTON AND HARPER
BETA = 0.1000 VNF = 0.3286 VF = 0.6714 DX = 0.1000 DC = 0.3759
PEACTIVITY CHANGES, DELTA K
     surn = 0.02756 exp = 0.01456 sare = 0.02000 total = 0.06212
FUEL ELEMENT VOLUME PRACTIONS
    CLADDING FUEL REGION HEAT PIPE WALLTWICK
                                                     VAPOR
                 0.7505
                                        0.0998
                            0.2495
                                                      0.1497
HEXAGONAL COPNER COPPECTION FACTOR =1.0642
NUMPER OF HEAT PIPES = 86.1780
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 162
TEMPERATURE SUMMARY, DEGREE KELVIN
     MAXIMUM FUEL DELTA T = 106.4
     AMS DELTA T ACCROSS HEAT PIPE WALL = 12.0
     AVERAGE FUEL TEMPERATURE #1647.4
     MAKIMUM FUEL TEMPERATURE =1724.3
BURN FRACTION OF U235 #0.0459
Fission density (Fissions/cm++3) = 4.960e+20
FUEL EMELLING, MOLUME % = 0.43 x 3 x 1.27
REACTOR DIMENSIONS! METERS
                                    FUEL ELEMENT DIMENSIONS, MM
  0.3759 COME DIAMETER
                                       28.04 WIDTH ACCROSS HEX FLATS
                                       29.44 EQUIV. FUEL ELEMENT DIA
  0.3759 come Height
  0.6059 REACTOR DIAMETER
                                       29.44 EQUIV. FUEL REGION D.D.
  0.5859 REACTOR HEIGHT
                                       14.71 HEAT PIPE G.D.
  0.1000 PEFLECTOR THICKNESS
                                       11.39 VAPOR DIAMETER
  1.0000 Pips Lensth dutside meactom 101.90 vapum amma, hm++2
  1.4809 TOTAL HEAT PIPE LENGTH
  1.5859 DVERALL REACTER THEAT PIPE LENGTH
```

#### REACTOR NEIGHTS: MILDGRAMS

297.3 FUEL, 0235 MASS = 150.8

322.4 REFLECTOR

166.2 HEAT PIPES, HT/UNIT LENGTH (KG/M) = 112.25

33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)

57.3 support structure (7% or reactor wt).

#### 876.3 TOTAL PEACTOR + HEAT PIPES

 $53.04~{
m MaxMe} + 3$  and powe in fuguspace  $10.19~{
m FW}$  power per Heat Pipe 99.95 MUZM++2,HTPIPE AXIAL HT FLUX - 0.757 MUZM++2,HTPIPE PAD HTFLX \*\*\*\*\*\*

```
1.650 (PR) REACTOR POWER, MW (MCORE) (1,2/UC, UD2) CORE #MO60UD2 1600. (THP) HEAT PIPE TEMP, DEG K (MREF) (1,2/BE, BED) REFLECTOR #BED
 3650. (TIME) LIFETIME, DAYS (KMP) (1,2,3/NB, MO, W) HEAT PIPE =MD
1.00 (SLD) CORE L/D MATID (KVAPOR) (1,2/LI, NA) VAPOR =LI
   10.0 (gaxe) axial at flux; ku/cm2 (ioptn) (1;2) OPTION
   200. (DTFMAX) MAX FUEL DELTA T.DEG K
  1.00 (HPL1) PIPE EXTENSION M
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
   TYPE IN ANY OF FOLLOWING : DOORE (M) MREF (M) UNFT FRETA NPIPE ..STOP
NPIPE=210. N. N STOP
                        210 (NPIPE) NO. OF HEAT PIPES
               BETA UC UCD ALFA PKAUG BMIN DXMIN COMGAP ENDGAP
            0.100 0.006 0. 0.600 1.500 0.050 0.080 0.015 0.005
    Type: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
vc≈0.005 stop
  SLD INDEX #
  \nu_{\text{NF}} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
   pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 p_{CH} = 0. 0.574 0.401 0.327 0.282 0.252 0.230 0.213 0.199 0.188
SO...PT DESIGN FOR PRES LAYTON AND HARPER, NPIPE=210
 BETA =0.1000 UNF =0.3280 UF =0.6720 DX =0.1000 DC =0.3756
  REACTIVITY CHANGES, DELTA K
           _{\text{BURN}} = 0.02760 gxp = 0.01456 sage = 0.02000 TOTAL = 0.06216
  FUEL ELEMENT VOLUME FRACTIONS
          CLADDING FUEL REGION HEAT PIPE WALL+WICK VAPOR
0. 0.7504 0.2496 0.0998 0.1497
  HEXAGONAL CORNER CORRECTION FACTOR #1.0643
  NUMBER OF HEAT PIPES = 86.2171
    MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 210
  TEMPERATURE SUMMARY DEGREE KELVIN
           MAXIMUM FUEL DELTA T = 82.1
           ANG DELTA T ACCROSS HEAT PIPE WALL = 9.2
                                                                                                                   ORIGINAL PAGE IS
            AVERAGE FUEL TEMPERATURE =1636.6
           MAXIMUM FUEL TEMPERATURE #1696.0
                                                                                                                  OF POOR QUALITY
  FURN FRACTION OF U235 =0.0460
  Fission Density (Fissions/cm++3) = 4.968e+20
  FUEL SWELLING, VOLUME % = 0.37 x3 = 1.11
                                                                     FUEL ELEMENT DIMENSIONS, MM.
  REACTOR DIMENSIONS, METERS
                                                                      24.62 WIDTH ACCROSS HEX FLATS
      0.3756 COPE DIAMETER
      25.85 EQUIV. FUEL ELEMENT DIA

0.5856 PEACTOR HEIGHT 12.92 HEAT PIPE O.D.

0.1000 REPLECTOR THICKNESS 10.00 PIPE LENGTH OUTSIDE TO 1.000 PIPE LENGTH PIPE TO 1.000 PIPE PIPE PIPE TO 1.000 PIPE PIPE TO 1.000 PIPE PIPE TO 1.000 PIPE PI
      1.4805 TOTAL HEAT PIPE LENGTH
      1.5856 DUERALL REACTORTHEAT PIPE LENGTH
  REACTOR WEIGHTS, KILDGRAMS
                         297.0 FUEL, 0235 MASS = 150.6
                          322.1 REFLECTOR
                         166.2 HEAT PIPES, MT/UNIT LENGTH (KG/M) = 112.24
                          33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg) 57.3 SUPPORT STRUCTURE (7% OF REACTOR WT)
                         875.5 TOTAL REACTOR + HEAT PIPES
```

53.11 MW/M++3,AMG POWR IN FUELSPACE 7.86 KW.POWER PER HEAT PIPE 99.96 MW/M++2,HTPIPE AXIAL HT FLUX 0.666 MW/M++2,HTPIPE RAD HTFLX

```
*************
Page No. 13 5-18-78
                       TYPE NEW INPUT! PROT. MHPES ... STOP
PRES. ETOP
                                -(Kcome) (1⋅2/Uc⋅Uo2) come ==Mo60Uo3
2.000 (ви) менстой ромей ни
```

1600. (THP) HEAT PIPE TEMP+DEG K (KREE) (1-2/BE+BEG) REPLECTOR FREG 3650. (TIME) LIFETIME DAVE (KMP) (1.2.37NB MOSH) HEAT PIPE FMO 1.00 (sup) come u/p matto (KUARDA) (1,2/LI,NA) NARDA EL I 10.0 (paxe) Asiac HT FEU/SHUZCH2 (IDPTN) (1.2) DPTION

200. (DIFMAX) MAX FUEL DELTA TIDEG K

1.80 (HPL1) PIPE FETENSIONSM

NOTE: OPTIONS ARE: 1-code PT DESIGN: 2-specified Design TYPE IN ANY OF FOLLOWING : DCORE(M) XREF(M) WHAT FRETA NPIPE ... STOP NETERALIO STOP

210 (NPIPE) NO. OF HEAT PIPES

VC VCD PETA ALEA PRAMA SMIN DYMIN COMMAP ENDSAP 0.100 0.006 0. 0.600 1.500 0.050 0.080 0.015 0.005 TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP υσ≖0.005 **εταρ** 

SUD INDEX #

 $\nu_{NF}$  = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000 pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.  $p_{CH} = 0.$  0.632 0.442 0.360 0.311 0.278 0.253 0.234 0.219 0.207 

GO

**BETA**  $\pm 0.1000$  PMF  $\pm 0.3566$  PF  $\pm 0.6434$  DX  $\pm 0.1000$  DC  $\pm 0.3893$ REACTIVITY CHANGES: DELTA K

 $p_{\text{UPN}} = 0.03138 \text{ exp} = 0.01456 \text{ same} = 0.02000 \text{ TOTAL} = 0.06594$ FHEL ELEMENT VOLUME PRACTIONS

CLADDING FUEL PERSON HEAT PIPE WALLTWICK VAPOR 0.1126 0.7185 0.2815 0.16890.

Heragonal compre commection mactom =1.0825 NUMBER OF HERT PIPES = 92.2398

MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIRES H

TEMPSHATURE SUMMARY DEGREE KELVIN

MAXIMUM FUEL DELTA T = 87.8 ANG DELTA T ACCROSS HEAT FIRE NAUL = 10.8 AMERAGE FUEL TEMPERATURE =1640.1 MARINUM FUSL TEMPERATURE =1704.0

ORIGINAL PAGE 13 OF POOR QUALITY

BURN FRACTION OF 0235 =0.0523 Fission pansity (Fissions/cm++3) = 5.648e+20 FUEL FUELLING PUOLUME % = 0.

```
PERCTOR DIMENSIONS: METERS
                                  FUEL ELEMENT DIMENSIONS. MM
                                      25.52 NIDTH ACCRESS HEX FLATS
 0.3393 come blametem
                                       26.80 EQUIV. FUEL ELEMENT DIA
  0.3893 come Hatchi
                                      26.80 EDUIV. FUEL MEGION O.D. 14.22 HEAT PIPE O.D.
  0.6193 REACTOR DIAMETER
  0.5993 PEACTOR HEIGHT
                                      11.01 VAPOR DIAMETER
  0.1000 PEFLECTOR THICKNESS
  1.0000 PIES LENGTH DUTSIDE REACTOR 95.26 VARGE AREA: MM++2
  1.4943 TOTAL HEAT PIPE LENGTH
  1.5993 OVERALL REACTOR HEAT PIPE LENGTH
```

PEACTOR WEIGHTS: KILOGRAMS

316.6 FUEL: U235 MASS = 160.5

PEFLECTOR 341.3

203.3 HEAT PIPES, UT/UNIT LENGTH (KG/M) = 136.03

33.0 CONTROL SYSTEM CASSUME CONSTANT # 33 KG)

68.6 SUPPORT STRUCTURE (7% OF REACTOR WT)

956.7 TOTAL REACTOR + HEAT FIRES

60.37 Mu/M++3%AUG ROUR IN FUELSPACE 9.52 MW\*POWER PER HEAT PIPE 99.98 NU/MulletPihteles Avial at sluv=0.787 NU/MulletPihtels Pat atslv\*\*\*\*\*\*\*

TYPE GO OF STOP

```
PROP NO. 14 5-18-78
                        TYPE NEW INPUT: PRE1. KHPE2 ... STOP
PRE4. TTOP
```

```
4.000 (PP) PEACTOR POWER-MN (KCORE) (1.2/UC.UG2) CORE =MG60UG2
1600. (THE) HEAT SIPL TEMP. DEG K (KREF) (1.2/28.280) PEPLECTOR RECO
3450. (TIME) LIFETIME DATE (KHAP (1.2.37NE MO) WEAT FIRE AMO
1.00 (SUD) CORE LTD PATIO (KMAPOR) (1.27LI)NA) MAROR FLI
10.0 (days) axias at provide/cm2 (ideth) (1:2).
                                                            OPTION
                                                                       =2
 200. (DTFMAY) MAX FUEL DELTA TIDES K
1.00 (HPL1) PIPE EXTENSION M
```

NOTE: OPTIONS ARE : 1-cope PT DESIGN: 2-specified Design TYPE IN ANY OF FOLLOWING : DODRE(M) MARF(M) MART FRETA NPIPE ... STOP NPIPERSON STOP

266 (NPIPE) NO. OF HEAT PIPES

RETA MC MCD ALFA PHAME BMIN DXMIN CORSAP ENDMAP 0.100 0.005 0. 0.600 1.500 0.050 0.080 0.015 0.005 TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKANGES, ETC ...STOP  $\nu_{0}=0.004$  stop

BUD INDEX #  $v_{NF}$  = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000 pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ♦.  $p_{CH} = 0.$  0.890 0.624 0.508 0.439 0.392 0.358 0.331 0.310 0.292 ullet ullet

**30** zera = 0.1000 vas = 0.4720 vs = 0.5280 px = 0.1000 pc = 0.4554REACTIVITY CHANGES, DELTA K

 $z_{\text{UPN}} = 0.04777 \text{ exp} = 0.01456 \text{ same} = 0.02000 \text{ total} = 0.08233$ FUEL FLEMENT MOLUME FRACTIONS

FUEL PEGION HEAT PIPE MALLTHICK 0.5890 0.4110 0.1644 0.2466 0.

HEXAGONAL CORNER CORRECTION FACTOR #1.1840

NUMBER OF HEAT PIPES = 115.0334 MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 266

TEMPERATURE SUMMARY DEGREE MELNIN

MAXIMUM FUEL DELTA T = 86.5 ANG DELTA T ACCROSS HEAT PIPE HALL # 14.6 ORIGINAL PAGE IS AMERAGE FUEL TEMPERATURE =1643.4 MAKIMUM FUEL TEMPERATURE =1708.3

OF POOR QUALITY

BURN FRACTION OF U235 =0.0796 Fission bensity (Fissions/CM++3) = 8.598e+20 FUEL EMELLING PUBLISHE % = 0.

```
PERCTOR DIMENSIONS: METERS FUEL ELEMENT DIMENSIONS: MM

0.4554 core piameter 26.54 with accross hex

0.4554 core piameter 27.97 error.
                                           26.54 WILTH ACCROSS HEX FLATS
  0.4554 come Height
                                           27.87 EDUID. FUEL ELEMENT DIA
  0.6854 PEACTOR DIAMETER
                                           27.87 EQUIV. FUEL PEGION C.D.
  0.6654 PEAGTOR HEIGHT
                                          17.87 HEAT PIPE O.D.
  0.1000 PEFLECTOR THICKNESS
                                           13.84 VAPOR DIAMETER
  1.0000 PIPS LENGTH OUTSIDE PEACTOR 150.41 VAPOR AREA: MM++2
  1.5604 TOTAL HEAT PIPE LENGTH
  1.6654 DUERALL PEACTOR HEAT PIPE LENGTH
```

# REACTOR NEIGHTS: KILDSPAMS

416.0 FUEL: 0235 MASS = 210.9 448.0 PEFLECTOR 424.5 HEAT PIPES, WT/UNIT LENGTH (KG/M) = 272.0533,0 control system (Assume constant = 33 kg) 92.1 furport structure (7% or reactor wt).

1407.5 TOTAL REACTOR + HEAT PIPES

91.91 MU/M\*\*Reads FOUR IN FUELSPACE 15.04 KNEPCUER FER HEAT FIRE 99.98 MUZM++2.HTPIPE AZIAL HT FLUX - 0.760 MUZM+2.HTPIPE PAD HTFLY \*\*\*\*\*\*\*\*\*\*\*\*\*

TYPE GO OF TIOP

```
. . . . .
PROF NO. 15 5-18-78 TYPE NEW INPUT: PREI. KHPE2 ...STOP
PRE0.2 THP=1750. STOP
                                 (KCOPE) (1:2/UC:UO2) COPE #MO60UO2
 0.200 (PP) REACTOR POHER MH
 1750. (THP) HEAT PIPE TEMP*DES N. (MREP) (1.2/38/380) PEPLECTOR #380
 3650. (TIME) LIFETIME DAYS (KMP) (1.2.3/NB MO N) MERT PIPE MMD (KMPDR) (1.2/LI:NA) MAPOR MLI
                                   (KVAPOR) (1.2/LI.NA) VAPOR =LI
(IOPTN) (1.2) OPTION =2
  10.0 (CARL) ARIAL HT FLURIKH/CH2 (IDPTN) (1.2)
                                                                  =2
                                                       OPTION
  200, (DTPMAX) MAY FUEL DELTA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
 NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCORE(M) MREP(M) MART PRETA NPIPE .. STOP
NPIPE=84 STOP
              84 (NPIPE) NO. OF HEAT PIPES
              UC UCD ALPA PRAVG THIN DYMIN CORGAP ENDGAP
        BETA
      0.100 0.004 0. 0.600 1.500 0.050 0.000 0.015 0.005
  TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
νσ=0.012 εταρ :
 SLD INDEX =
 \nu_{\rm NF} = 0.100 \, 0.200 \, 0.300 \, 0.400 \, 0.500 \, 0.600 \, 0.700 \, 0.800 \, 0.900 \, 1.000
 pg ≈ 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
 p_0 = 0 0.207 0.142 0.115 0.099 0.088 0.081 0.074 0.070 0.066
+ + + + + + + + + + + + TYPE GO OM STAMT DVEM + + + + + + + + + + + + +
an.
 pgTA = 0.1000 UNF = 0.1501 UF = 0.8499 px = 0.1000 pc = 0.3115
 PERCTIVITY CHANGES! DELTA K
      BURN = 0.00464 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.04076
 FUEL ELEMENT MOLUME FRACTIONS
     CLADDING FUEL REGION HEAT PIPE
                                          MALLTHICK
                                                      VARDO
      0. 0.9558 0.0448 0.0177 0.0265
 MEXAGONAL CORNER CORRECTION FACTOR #1.0020
 NUMBER OF HEAT FIRES # 31.5836
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES #
 TEMPERATURE SUMMARY DEGREE KELVIN
      HASIMUM FUEL DELTA T = 75.2
      AMS DELTA T ACCROSS HEAT PIPE WALL # 3.4
      AMERAGE FUEL TEMPERATURE #1778.4
                                                           ORIGINAL PAGE IS
      MAYIMUM FUEL TEMPERATURE =1830.3
                                                           OF POOR QUALITY
 BURN FRACTION OF U235 =U.0077
 Fission Density (Fissions/CM++3) = 8.345e+19
 FUEL ENELLING MOLUME % = 5 1.4
 REACTOR DIMENSIONS: METERS
0.3115 CORE DIAMETER
                                    FUEL ELEMENT DIMENSIONS, MM
                                        32.18 HIDTH ACCROSS HEX FLATS
                                        33.79 EDUIN. FUEL ELEMENT DIA
   0.3115 COME HEIGHT
                                       33.79 EQUIV. FUEL PEGION C.D.
   0.5415 PEACTOR DIAMETER
                                        7.11 HEAT PIPE D.D.
   0.5215 REACTOR HEIGHT
   0.1000 PEFLECTOR THICKNESS
                                        5.51 VAPOR DIAMETER
   1.0000 FIRE LENSTH OUTSIDE PEACTOR 23.80 VAPOR AREA: MM++2 1.4165 TOTAL HEAT FIRE LENSTH
   1.5815 OMERALL MEACTOR HEAT PIPE LENGTH
 PERCTOR NEIGHTS: MILOSPAMS
             214.3 FUEL, 0235 MASS = 108.7
             240.2 MERLECTOR
              19.3 HEAT PIPES, MIZUNIT LENGTH (RGZM) = 13.60
              33.0 CONTROL SYSTEM (ASSUME CONSTANT # 33 Kg)
              35.5 SUPPORT STRUCTURE (7% OF REACTOR NT)
             542.2 TOTAL REACTOR + HEAT PIPES
```

8.92 Ma/M++3.ang pour in fuelspace 2.38 km.fouer for heat pire 100.04 Ma/M++2.atring asial at flux 0.442 Ma/M++2.atring pag atrix

```
************
```

```
PPOR NO. 16 5-18-78
                        TYPE NEW INPUT: PRES. KMPEZ ...STOP
PRED. 4 STOP
                                   (KCDMR) (1,2/UC,UD2) CDME #MD60UD3
 0.400 (PP) PEACTOR POHER MM
 1750. (THP) HEAT PIPE TEMPIDES K (KREE) (1.2/SEISES) REPLECTOR MORG
 3650. (TIME) LIPETIME DAYS
1.00 (SLD) COPE L/D RATIO
                                   (KHP) (1,2,3/ND, MD, W) HEAT PIPE THE
                                   (MYAPOR) (1,2/LI,NA) VAPOR
  10.0 (DAYL) AKIAL HT FLUKIKH/CH2 (IDPYN) (1:2)
                                                        OPTION
                                                                 =2
  200. (DTFMAK) MAX FUEL DELTA TIDES K
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING ! DCOPE(M) YPEF(M) UNFT FRETA NPIPE ..STOP
NPIPE=84 STOP
              34
                 (NPIPE) NO. OF HEAT PIPES
                     VCD ALFA PKAVG BMIN DXMIN COPGAP ENDGAP
        BETA
              VC
      0.100 0.012 0.
                          0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: STOP: OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
STOP
ELD INDEX =
 w_{\rm MF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 0.900 1.000
 p_{0} = 0.299 \ 0.326 \ 0.363 \ 0.412 \ 0.475 \ 0.562 \ 0.694 \ 0.961 \ 1.754 \ \bullet.
 p_{CH} = 0. 0.293 0.201 0.163 0.140 0.125 0.114 0.105 0.098 0.093
+ + + + + + + + + + + TYPE 30 OR START DIVER + + + + + + + + + + +
                            \nu_F = 0.8152 px = 0.1000 pc = 0.3214
BETA = 0.1000 UNF = 0.1848
 REACTIVITY CHANGES! DELTA H
     _{\text{BURN}} = 0.00331 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.04493
 FUEL ELEMENT VOLUME FRACTIONS
     CLAPDING FUEL PEGION MENT PIPE 0.0-15
                                          HALL+WICK
                                                      VAPOR
                                        0.0333
                                                     0.0500
 HEYARONAL CORNER CORRECTION FACTURE 1.0070
 NUMBER OF HEAT FIRES # 46.5570
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES =
 TEMPSHATURE SUMMARY, DEGREE MELVIN
                                                      ORIGINAL PAGE IS
     MAXIMUM FUEL DELTA T = 110.8
                                                      OF POOR QUALITY
      ANG DELTA T ACCROSS HEAT PIPE MALL # 6.5
      AVERAGE FUEL TEMPERATURE =1793.5
      MAXIMUM FUEL TEMPERATURE #1870.7
 BURN FRACTION OF 0235 \pm 0.0147
 Fission density (Fissions/cm++3) = 1.585e+20
 FUEL SHELLING PUBLISHE % = 1 2.4
 PERCTOR DIMENSIONS. METERS
                                   FUEL ELEMENT DIMENSIONS! NM
   0.3214 come DIAMETER
                                       33.19 WIDTH ACCROSS HEX PLATS
   0.3214 come нетонт
                                        34.85 EQUIP. FUEL ELEMENT DIA
   0.5514 REACTOR DIAMETER
                                        34.85 EQUIV. FUEL REGION D.D.
   0.5314 PEACTOR HEIGHT
                                       10.06 HEAT PIPE D.D.
                                        7.79 VAPOR DIAMETER
   0.1000 PEFLECTOP THICKNESS
   1.0000 PIPE LENGTH DUTSIDE REACTOR 47.56 VAROR AREA, 66
   1.4264 TOTAL HEAT PIPE LENGTH
   1.5314 OVERALL REACTOR HEAT PIPE LENGTH
 PEACTOR WEIGHTS: KILDSPAMS
             225.6 FUEL: U235 MASS = 114.4
             251.9 PERLECTOR
              38.8 HEAT PIPES, WT/UNIT LENGTH (kg/m) = 27.22
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 kg)
              38.5 SUPPORT STRUCTURE (7% OF REACTOR NT)
             587.9 TOTAL PEACTOR + HEAT PIPES
```

16.94 MU/M++3.AUG FOUR IN FUELSPACE - 4.76 KM-POWER PER HEAT PIPE 99.92 MU/M++2.HTPIPE BAD HYPLX

\*\*\*\*\*

THE -- --

```
PROD NO. 17 5-18-78 TYPE NEW INPUT: PRE1. KHP=2 ...STOP
PR=0.7 STOP
 0.700 (PP) REACTOR POHER MH
                                 (KCOPE) (1,2/UC,UO2) CORE =MO60UD2
 1750. (THP) HEAT PIPE TEMP+DEG K (KREF) (1.2/3E-3ED) PEFLECTOR #8ED
 3650. (TIME) LIPETIME DAYS (KMP) (1:2:3/NB:MD:W) HEAT PIPE MMD (KMPPOM) (1:2/LI:NA) MAPOR HLI
 10.0 (PAKE) AKIAL HT PLUKIKH/CH2 (IDPTN) (1:2)
                                                        OPTION =2
 200. (DIFMAY) MAY FUEL DELTA TIDES H
 1.00 (HPL1) PIPE EXTENSION M
NOTE: OPTIONS ARE: 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
 TYPE IN ANY OF FOLLOWING : DODRE (M) MREF (M) UNFT FRETA NPIPE .. STOP
NPIPE=120 STOP
            120 (NPIPE) NO. OF HEAT PIPES
        BETA UC UCD ALFA PKAUS BMIN DXMIN CURSAP ENDSAP
      0.100 0.012 0. 0.600 1.500 0.050 0.080 0.015 0.005
  TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
vc=0.008 grop
SLD INDEX =
v_{NF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
 pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
p_{CH} = 0, 0.380 0.263 0.214 0.184 0.165 0.150 0.139 0.130 0.122
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO ON START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
40
BETA = 0.1000 UNF = 0.2264 UF = 0.7736 DX = 0.1000 DC = 0.3348
REACTIVITY CHANGES! DELTA K
     p_{UPN} = 0.01435 \text{ gap} = 0.01612 \text{ sape} = 0.02000 \text{ total} = 0.05047
 FUEL ELEMENT VOLUME PRACTIONS
    CLADDING FUEL REGION HEAT PIPE HALL+WICK
                                                     VAPOR
     0. 0.8665 0.1335 0.0534 0.0801
 HEXAGONAL CORNER CORRECTION FACTOR =1.0180
 NUMBER OF HEAT PIPES = 61.1476
  MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES # 120
 TEMPERATURE SUMMARY, DEGREE KELVIN
                                                         ORIGINAL PAGE IS
     MASINUM FUEL DELTA T = 101.9
     AUG DELTA T ACCROSS HEAT PIPE HALL # 7.7
                                                        OF POOR QUALITY
     APERAGE FUEL TEMPERATURE =1791.7
     MAXIMUM FUEL TEMPERATURE #1863.4
 BURN FRACTION OF 0235 \pm 0.0239
 FISSION DENSITY (FISSIONS/CM++3) = 2.584e+20
 FUEL SWELLING POLUME % = $2 4.3
 REACTOR DIMENSIONS: METERS
0.3348 CORE DIAMETER
                                   FUEL ELEMENT DIMENSIONS, MM
                                   29.00 WIDTH ACCROSS HEX FLATS
   0.3348 come Height
                                       30.44 ERUIV. FUEL ELEMENT DIA
                                      30.44 EQUIV. FUEL REGION O.D.
   0.5648 PEACTOR DIAMETER
   0.5448 PEACTOR HEIGHT
                                       11.12 HEAT PIPE O.D.
  0.1000 PEFLECTOR THICKNESS
                                       8.62 PAPOR DIAMETER
   1.0000 FIRE LENGTH DUTSIDE REACTOR 58.31 VAPOR AMEA: MM++2
  1.4398 TOTAL HEAT PIPE LENGTH
1.5448 OVERALL REACTOR HEAT PIPE LENGTH
 PEACTOR WEIGHTS: MILLOSPAMS
             242.3 FUEL: U235 MASS = 122.8
             268.5 PEFLECTOR
              68.5 Heat Pipes, William Length (Mg/M) = 47.58
              33.0 CONTROL SYSTEM (ASSUME CONSTANT # 33 Mg)
             42.9 SUPPORT STRUCTURE (7% OF REACTOR WT)
             655.2 TOTAL PEACTOR + HEAT PIPES
```

27.62 MM/M++3.AMS POWD IN FUELSPACE 5.83 KM.POWER PER HEAT PIPE 100.05 MM/M++2.HTPIPE AMIAL HT FLUX 0.644 MM/M++2.HTPIPE RAD HTPLX

```
InL
                           _____
                         TYPE NEW INPUT: PR#1. KHP#2 ...STOP
PROS NO. 18 5-18-78
PREI. STOP
                                  (KCOPE) (1,2/UC,UO2) COPE =MO60UO2
 1.000 (PA) REACTOR POWER MM
 1750. (THP) HEAT PIPE TEMP+DES K (KPEF) (1,2/36,360) REPLECTOR #360
 3650. (TIME) LIFETIME, DAYS (KHP) (1,2,3/N3,MD; W) HEAT PIPE MMD
1.00 (FLD) CORE L/D RATIO (KMAPOR) (1,2/LI,NA) MAPOR = T
  1.00 (FLD) COME L/D MATIO
  10.0 (DAYL) AMIAL HT FLUMIKH/CHE (IDPTN) (1:2)
                                                                   25
  200. (DTFMAX) MAX FUEL DELTA TIDES K
  1.00 (HPL1) PIPE EXTENSIONSM
 NOTE, OPTIONS ARE : 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
  TYPE IN ANY UP FOLLOWING : DCOPE(I) MREF(M) WHAT FRETA NPIPE .. STOP
NETPER162 STOP
             162
                  (NPIPE) NO. OF HEAT PIPES
                                                DXMIN COPGAP ENDGAP
              UC UCD ALFA PKAUG BMIN
        BETA
                           0.600 1.500 0.050 0.080 0.015 0.005
      0.100 0.008 0.
  TYPE: STOP. OR NEW CONSTAN : IE. MC=0. PKAMG=2. ETC ...STOP
vc=0.006 stop
 SED INDEX #
 \nu_{NF} = 0.100 0.200 0.300 0.400 0.500 0.600 0.700 0.800 \nu.900 1.000
  p_{\rm C} = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 \bullet.
 p_{CH} = 0. 0.449 0.313 0.255 0.220 0.197 0.179 0.166 0.155 0.146
◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ TYPE GO OR START OVER ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆ ◆
30
 BETA =0.1000 PMF =0.2630 PF =0.7370 DX =0.1000 DC =0.3482
 REACTIVITY CHANGES! DELTA K
      pupn = 0.01915 \text{ exp} = 0.01612 \text{ safe} = 0.02000 \text{ total} = 0.05527
 FUEL ELEMENT VOLUME PRACTIONS
                                          MALLTHICK
                                                      シムクロ内
                FUEL REGION HEAT PIPE
     CLADDING
                                          0.0705
                  0.8238
                              0.1762
                                                      0.1057
      0.
 MEXAGONAL CORNER CORRECTION FACTOR =1.0315
 NUMBER OF HEAT PIPES = 71,2219
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES # 162
 TEMPERATURE SUMMARY, DEGREE KELVIN
      MAXIMUM FUEL DELTA T = 87.9
      AMS DELTA T ACCROSS HEAT PIPE MALL = 7.8
                                                       ORIGINAL PAGE IS
      AVERAGE FUEL TEMPERATURE =1787.1
                                                       OF POOR QUALITY
      MAXIMUM FUEL TEMPERATURE =1849.7
 BURN FRACTION OF 0235 \pm 0.0319
 FISSION DENSITY (FISSIONS/CM++3) = 3.447e+20
 FUEL SWELLING , DOLUME % = 45 ~ 5.7
                                     FUEL ELEMENT DIMENSIONS, MM
 PEACTOR & MENSIONS: METERS
                                        25.97 WIDTH ACCROSS HEX FLATS
   0.3482 COME DIAMETER
                                        27.27 EQUIV. FUEL ELEMENT DIA
   0.3482 CORE HEIGHT
                                               EQUIV. FUEL REGION O.D.
HEAT PIPE O.D.
                                        27.27
   0.5782 PEACTOR DIAMETER
                                        11.45
   0.5582 REACTOR HEIGHT
                                         8.87
   0.1000 PEFLECTOR THICKNESS
                                               VAPOR DIAMETER
   1.0000 FIRE LENGTH OUTSIDE PEACTUR 61.74 VAPOR AREA, MM++2
   1.4532 TOTAL HEAT PIPE LENGTH
   1.5582 OVERALL PEACTOR+WEAT PIPE LENGTH
 PEACTOR WEIGHTS: KILOGRAMS
             259.4 FUEL, 0235 MASS = 131.5
             285.5 PEFLECTOR
              98.8 HEAT PIPES, MT/UNIT LENGTH (KG/M) = 68.02
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 Kg)
```

724.1 TOTAL REACTOR + HEAT PIPES

36.84 MU/M++3.AUG POUR IN FUELSPACE 6.17 KN:POUER PER HEAT PIRE 99.98 MU/M++2.HTPIRE AXIAL HT FLUX 0.637 MU/M++2.HTPIRE RAD HTFLX +++++++++++

47.4 SUPPORT STRUCTURE (7% OF REACTOR WT)

```
DIPPOS NO. 1 G-21-78 TYPE NEW INPUT: PRE1. KHH=2 ...STOP
pp=2; thp=1750, time=3650, kcche=5 kref=2 kvapor=1 ioptn=2 stop
 2.000 (PR) REACTOR POWER, MW (KCORE) (1,2/UC, UD2) CORE =MD60UD2
 1750. (THP) HEAT PIPE TEMP, DEG K (KPEF) (1,2/3E,3ED) REFLECTOR #3ED
 3650. (TIME) LIFETIME, DAYS (KHP) (1,2,3/NB, MD, W) HEAT PIPE #MD 1.00 (SLD) CORE L/3 RATIO (KVAPOR) (1,2/LI, NA) VAPOR #LI
   10.0 (daxe) Axiae ht flux,kh/cm2 (ioptn) (1,2)
                                                         DPTIDN
                                                                    =2
  206. (DTFMAX) MAX FUEL DELTA TIDEG K
  1.00 (HPL1) PIPE EXTENSION M
 NOTE: OPTIONS ARE : 1-CODE PT DESIGN: 2-SPECIFIED DESIGN
  TYPE IN ANY OF FOLLOWING : DOORE (M) XREF (M) UNFT FRET: NPIPE ..STOP
NOTPE#210 STOP
             210 (NPIPE) NO. OF HEAT PIPES
       %ETA VC VCD ALFA PKAVG BMIN DKMIN CORGAP ENDGAP 0.100 0. 0.050 0.600 1.500 0.050 0.080 0.015 0.005
   TYPE: STOP, OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
vc=0.005 vcb=0. stop
 SED INDEX =
 v_{NF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
  pc = 0.299 \ 0.326 \ 0.363 \ 0.412 \ 0.475 \ 0.562 \ 0.694 \ 0.961 \ 1.754 .
 ъсн = 0. 0.632 0.442 0.360 0.311 0.278 0.253 0.234 0.219 0.207
 + + + + + + + + + + + + TYPE GO OR START OVER + + + + + + + + + + + + +
 GO...ADJUST BETA FOR 3.33% SWELLING
 pera =0.1000 vnr =0.3566 vr =0.6434 px =0.1000 pc =0.3893
 REACTIVITY CHANGES: DELTA K
       BURN = 0.03138 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.06750
  FUEL ELEMENT VOLUME PRACTIONS
      CLADDING FUEL REGION HEAT PIPE HALL-WICK VAPOR
                 0.7185 0.2815 0.1126 0.1689
 HEXAGONAL CORNER CORRECTION FACTOR =1.0825
 NUMBER OF HEAT PIPES = 92.2398
   MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 210
 TEMPERATURE SUMMARY, DEGREE KELVIN
       MAXIMUM FUEL DELTA 7 = 87.8
       ANG DELTA T ACCROSS HEAT PIPE WALL = 10.8 ORIGINAL PAGE IS
       AVERAGE FUEL TEMPS ATURE =1790.1
                                                       OF POOR QUALITY
       MAXIMUM FUEL TEMPERATURE =1854.0
  BURN FRACTION OF 0235 = 0.0523
 FISSION DENSITY (FISSIONS/CM++3) = 5.648z+20
 FUEL SHELLING , VOLUME % = 3.10 k3 = 9.3
                                FUEL ELEMENT DIMENSIONS. MM
 REACTOR DIMENSIONS, METERS
    0.3893 CORE DIAMETER
                                        25.52 WIDTH ACCROSS HEX FLATS
                                         26.80 EQUIV. FUEL ELEMENT DIA 26.80 EQUIV. FUEL REGION D.D.
    0.3893 come Height
    0.6193 REACTOR DIAMETER
    0.5993 REACTOR HEIGHT
                                         14.22 HEAT PIPE G.D.
   0.1000 PEFLECTOR THICKNESS 11.01 VAPOR DIAMETER
   1.0000 PIPE LENSTH DUTSIDE REACTOR 95.26 VAPOR WREA, MM++2
   1.4943 TOTAL HEAT PIPE LENGTH
1.5993 OVERALL REACTOR*HEAT PIPE LENGTH
 PEACTOR WEIGHTS: MILOGRAMS
              316.6 FUEL, 0235 MASS = 160.5
              341.3 REFLECTOR
              203.3 HEAT PIPES, WT/UN/T LENGTH (kg/m) = 136.03
              33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 kg)
62.6 SUPPORT STRUCTURE (7% OF REACTOR WT)
              956.7 TOTAL REACTOR + HEAT PIPES
   60.37 MM/M++3.4MG POWA IN FUELSPACE 9.52 KW;PDWER PER WEE PIPE
   99.98 MH/M++2;HTPIPE AXIAL HT FLUX 0.707 MH/M++2;HTPIPE RAD HTFLX
                             *****
```

TYPE GO OP END

Ť

```
(5C)
                              *****
   PROS NO. 3 6-14-78 TYPE NEW INPUT: PRE1. KHP=2 ...STOP
  STOP
m{V} 4.000 (PR) PEACTOR POWER:MW
                                     (Kcope) (1,2/UC,UD2) come ==MD60UD2
   1750. (THP) HEAT PIPE TEMP, DEG K. (KPEP) (1,2/SE)SEG) PEPLECTOR FRED.
   3650. (TIME) LIFETIME, DAYS (KHP) (1,2,3/NB, MO, W) HEAT PIPE =MO
1.00 (FLD) COME L/D MATIO (KVAPOR) (1,2/LI, NA) VAPOR =LI
    10.8 (cayl) Axial HT FLUX; KW/CM2 (IDPTN) (1;2)
                                                           OPTION
                                                                     =2
    200. (DIFMAX) MAX FUEL DELTA TYDEG K
    1.00 (HPL1) PIPE EXTENSIONSM
   NOTE, OPTIONS ARE: 1-CODE PT DESIGN, 2-SPECIFIED DESIGN
    TYPE IN ANY OF FOLLOWING : DOORE (M) MREF (M) UNFT FRETA NPIPE .. STOP
  NPIPE=264 STOP
                264 (NPIPE) NO. OF HEAT PIPES
          BETA UC UCD ALFA PKAUG BNIN DXMIN CORGAP ENDGAP
         0.200 0.004 0. 0.600 1.500 0.050 0.080 0.015 0.005
    TYPE: STOP) OR NEW CONSTANTS IE. VC=0. PKAVG=2. ETC ...STOP
  BETA=0.289 STOP
   SUD INDEX # 3
   v_{NF} = 0.100 \ 0.200 \ 0.300 \ 0.400 \ 0.500 \ 0.600 \ 0.700 \ 0.800 \ 0.900 \ 1.000
    pc = 0.299 0.326 0.363 0.412 0.475 0.562 0.694 0.961 1.754 ◆.
   p_{CH} = 0. 0. 2.720 0.747 0.538 0.443 0.385 0.345 0.315 0.292
   * * * * * * * * * * * * * * TYPE GO DR START DVER * * * * * * * * * * * *
  GO...ADJUST BETA TO LIMIT INDICATED SWELLING TO 3.33% (IE 10% SWELL.)
   pera =0.2890 v_{\text{NP}} =0.5331 v_{\text{F}} =0.4669 p_{\text{X}} =0.1000 p_{\text{C}} =0.5003
   REACTIVITY CHANGES, DELTA K
        BURN = 0.04075 EXP = 0.01612 SAFE = 0.02000 TOTAL = 0.07687
   FUEL ELEMENT VOLUME FRACTIONS
                   FUEL REGION HEAT PIPE MALLTHICK
                     0.6594
                                0.3406
                                             0.1363
                                                          0.2044
   HEXACONAL CORNER CORRECTION FACTOR =1.1230
   NUMBER OF HEAT PIPES = 123.4099
     MINIMUM PRACTICAL (OR SPECIFIED) NUMBER OF HEAT PIPES = 264
   TEMPERATURE SUMMARY, DEGREE KELVIN
        MAXIMUM FUEL DELTA T = 93.5
        AMS DELTA T ACCROSS HEAT PIPE WALL = 13.4
                                                           ORIGINAL PAGE IS
         AMERAGE FUEL TEMPERATURE =1794.5
                                                          OF POOR QUALITY
        MAXIMUM FUEL TEMPERATURE =1863.5
   BURN FRACTION OF U235 =0.0679
   FISSION DENSITY (FISSIONS/CM++3) = 5.794g+20
   FUEL SWELLING, MOLUME % = 2.35 /0.0 5
     Description of the second
                                       FUEL ELEMENT DIMENSIONS, MM
   REACTOR DIMENSIONS, METERS
                                           29.27 WIDTH ACCROSS HEX FLATS
     0.5003 CORE DIAMETER
                                           30.73 EQUIV. FUEL ELEMENT DIA 30.73 EQUIV. FUEL REGION O.D.
     0.5003 come Height
     0.7303 PEACTOR DIAMETER
     0.7103 REACTOR HEIGHT
                                           17.94 HEAT PIPE D.D.
                                           13.89 VAPOR DIAMETER
     0.1000 REFLECTOR THICKNESS
     1.0000 PIPE LENGTH OUTSIDE PEACTOR 151.58 VAPOR AREA, MM++2
     1.6053 TOTAL HEAT PIPE LENGTH
     1.7103 OVERALL REACTOR HEAT PIPE LENGTH
   REACTOR MEIGHTS: KILOGRAMS
                487.7 FUEL, 0235 MASS = 247.2
```

518.0 PEFLECTOR

436.8 Heat Pipes, ut/unit Length (kg/m) = 272.12

33.0 CONTROL SYSTEM (ASSUME CONSTANT = 33 kg)

103.3 SUPPORT STRUCTURE (7% OF REACTOR WT)

1578.8 TOTAL REACTOR + HEAT PIPES

61.94 MU/M++3.AUG POWR IN FUELSPACE 15.15 KW.POWER PER HEAT PIRE 99.96 MW/M++2,HTPIPE AXIAL HT FLUX - 0.694 MW/M++2,HTPIPE PAD HTFLX